Automated Approach for Compliance with NERC PRC-027-1 Requirements for Protection System Coordination of BES Elements

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***Abstract*— PRC-027-1 is an upcoming NERC Protection and Control Reliability Standard that is intended to ensure the continual maintenance of coordination for protection systems associated with Bulk Electric System (BES) elements. Expected to come into effect in October 2020, the PRC-027-1 Reliability Standard will require utilities that own protection systems installed to identify and isolate faults on BES elements, to establish formal procedures in a range of aspects to support maintenance of Protection System Coordination performance. One aspect of the requirements will mandate that applicable entities develop a process for the execution of Protection System Coordination Studies for protection systems associated with BES elements. These requirements can pose significant challenges to utilities and other applicable entities; in addition to the technical engineering effort associated with the execution of Protection System Coordination Studies, complying with PRC-027-1 also necessitates significant workflow management and data processing considerations.**

This paper discusses one potential approach to enable compliance with the PRC-027-1 requirements. This approach covers process and data management considerations and provides a framework workflow for the obtaining and comparison of fault currents, execution and review of coordination studies, and processing and documentation of results to support proof of compliance with the PRC-027-1 Reliability Standard. The central concept of the approach under discussion is the utilization of software-based automation in a number of key tasks. Firstly, determination, comparison, and recording of fault currents is achieved through the employment of custom-written applications interfacing with industry-standard power system simulation software. Secondly, the execution of large-scale Protection System Coordination Studies is largely automated through utilization of specialized scripts running within the simulation software packages. Thirdly, the vast amounts of data inherent in the Protection System Coordination Study results are processed in a manner that assists protection engineers in the identification and resolution of coordination issues. Finally, auditor friendly automated compliance summaries are generated that can be used as a record of compliance.

Keywords—protection; coordination; compliance; automation; NERC; PRC-027-1

I. Introduction

Protection systems are designed so that relays operate appropriately in relation to nearby devices. Ensuring that these protective devices are configured to operate in the intended sequence relative to adjacent protective devices to clear a fault on the network, is known as protection coordination. The upcoming NERC PRC-027-1 standard was implemented to ensure that protection coordination is maintained through the requirement of performing periodic coordination studies on a six-year cycle [1].

The standard provides three options for defining for which protective elements require coordination studies to be run:

- Option 1 – Perform coordination studies and develop mitigation plan to address issues for elements associated with BES equipment every six years
- Option 2 – Perform coordination studies and develop mitigation plan to address issues for elements associated with Bulk Electric System (BES) equipment connected to system buses that exhibit a fault current deviation of 15% or greater from a previously established baseline value. This process must be completed within a six-year period.
- Option 3 – Combination of the first two options

It is expected that utilities with large transmission systems will generally opt for Option 2, as it has the potential to reduce utility burden by limiting the number of coordination studies that need to be performed and reviewed. However, additional effort is imposed through the required tracking and comparison of fault currents against the baseline value. To perform PRC-027-1 compliance using this option, several aspects need to be considered including:

- Development of a process for PRC-027-1 evaluation to enable meeting of the compliance requirements within the specified six-year cycle.
- Definition and specification of the scope and technical criteria for the compliance studies to be conducted, including depth of backup protection studied and

extent of contingencies considered. Since the standard does not provide specific performance criteria, each utility would need to define the parameters of these coordination studies to satisfy their established protection philosophy.

- Methodology and criteria for performing the actual coordination studies, as well as the review and mitigation process.
- Utilization and maintenance of the short circuit model and evaluation platform to support fault current comparison and coordination studies.
- Establishment of baseline fault current values to be used for comparison, and the supporting data considerations to meet the standard requirements.
- Definition and development of the mechanisms necessary to enable tracking of compliance evaluation for each relevant bus over individual six-year cycles.

Considering the aspects listed above, meeting PRC-027-1 compliance can pose significant challenges to utilities, in terms of resource and effort concerns, as well as the need for workflow management and tracking to comply with the periodic cycles. In particular, the needed effort to conduct the coordination studies and reviews can be an appreciable burden, as evidenced by the removal of the requirement for an initial coordination study to be completed from earlier drafts of the PRC-027-1 standard, based on feedback from utilities [2].

The potential difficulties in meeting PRC-027-1 requirements present a compelling argument for the utilization of software automation to assist engineers in their work. It should be noted that automated tools and processes are not intended to replace engineer involvement but can instead mitigate the more repetitive study execution and data transfer tasks, enabling the engineer to focus on more technical tasks that require critical thinking, experience, and intuition.

This paper presents one potential approach to conducting PRC-027-1 compliance evaluation using the fault comparison option and explores addressing of the technical aspects identified above using software automation to mitigate the engineer effort burden. Aspects discussed in the following sections include network and protection modeling, fault baseline establishment, performing fault comparison and coordination studies, data management and reporting methodologies, and considerations of using the fault comparison option versus the simpler option of performing system-wide coordination studies.

II. Proposed Compliance Evaluation Process

In contrast to the simpler Option 1 in which all BES elements must be evaluated, the utilization of the more selective Option 2 necessitates two stages of evaluation to comply with PRC-027-1: a fault comparison to determine applicable elements on which to perform coordination studies, followed by the coordination studies themselves with review and mitigation plan. This generalized process can be seen in Fig. 1.

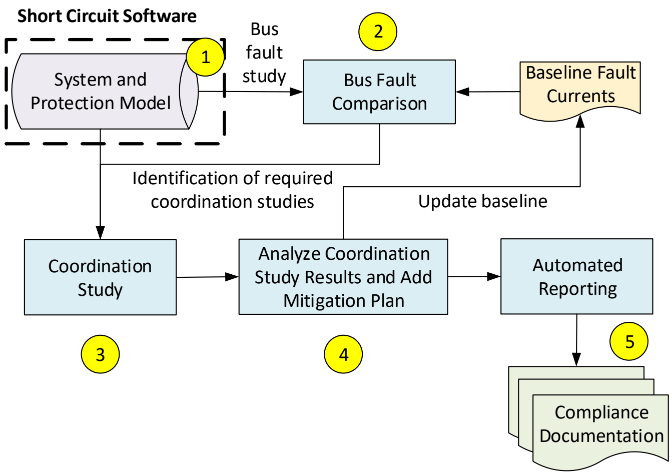

Fig. 1. General PRC-027-1 evaluation process

The proposed process discussed in this paper introduces the utilization of software automation to enable a more efficient and consistent application of this evaluation. The major tasks which can be improved through automation are labeled numerically in Fig. 1:

1) Maintenance and updating of the short circuit model (both system and protection) to be used for the bus fault comparisons and coordination studies. Automation tools can assist with the data entry and transfer of primary model parameters and secondary model device settings.

2) Execution of a bus fault study using the short circuit model and comparison of fault current values against an established baseline. From this comparison, cases requiring coordination study (deviation of 15% or greater) can be identified. Automated procedures can be developed to perform these tasks, assuming the short circuit software platform supports scripting.

3) Execution of the required coordination studies using the short circuit model according to the utility's protection philosophy. There are many different ways to perform coordination analysis, however, in order to automate coordination analysis, a systematic methodology is required that can be applied generally to all types of protection systems and network topologies. One such method is based on simulating protection operation behavior for a fault under specific network changes, using a protection simulation tool. Most advanced protection simulation tools support writing of macros/scripts to automatically simulate a large number of test cases, as well as enabling multiple network elements to be studied at once in a batch process.

4) Analysis of coordination study results and definition of mitigation plan to address identified issues. Automation-based coordination studies can generate very large amounts of data. Therefore, an automation-based processing of simulation output can assisting engineers in their review by consolidating and summarizing the simulation output into more intuitive forms, and prioritize the issues for them. The processed results summary can also provide template for engineers to document their mitigation plans in a standardized format.

5) Automated reproting tools to create audit-friendly compliance reports. Running systematic coordination studies, and utilizing standardized process for adding mitigation plan will facilitate creation of detailed compliance reports for the purpose of documentation of evidence.

In addition to the process tasks listed above, software tools can be utilized for the tracking of compliance progression for each applicable bus or BES element. This can give engineers a broad view of compliance completion as well as readily available indication of issues that may need to be addressed.

III. Primary Network and Protection System Modeling

With the requirement of periodic fault current comparisons and/or protection coordination studies, entities running PRC-027-1 evaluations will require access to accurate and up-to-date short circuit models, including functional protection representation. To support these requirements, utilities are moving towards maintaining system parameters in centralized databases and protection data in asset management applications.

The maintenance of up-to-date information in short circuit software has historically been a challenge to utilities. For primary model elements (transmission lines and transformers), processes are required to be in place for the calculation of parameters and updating of models, including potential communication considerations between planning and protection departments. Availability of data is a concern, as protection engineers may be required to support projects in a preliminary stage, before final equipment data is available.

The maintenance of the secondary (protection) model can be even more challenging, due to modeling requirements of short circuit software platforms. The representation of relays on these software platforms, including device settings, functional trip logic, and verification of model operation, can require significant detail and processes to ensure correct and up-to-date relay representation on a continual basis.

The proposed approach to mitigate these concerns is the consolidation and integration of data sources with the short circuit model required for PRC-027-1 evaluation:

- System and protection data should be maintained within centralized repositories such as database applications. This provides a single, presumably widely accessible, location for specific data, reducing the burden on engineers to find required information.

- The data sources mentioned above should be integrated in an established process to enable transfer of information between sources or with external applications. Specific to the PRC-027-1 process, the centralized repositories containing primary system and secondary protective relay data should be set up for automation-assisted import to the short circuit and simulation software.

Both aspects for data applications contain process and data management considerations that can provide benefits beyond supporting PRC-027-1 evaluation. For the integration of sources in particular, software-based automation can play a central role to enable the smooth transition of data from one form to another.

Taking the case of the secondary (protection) model, automation tools can mitigate the burden required in creating and updating relay models in short circuit software platforms. A hypothetical integrated process utilizing software automation is presented in Fig. 2 with the following tasks:

1) Interfacing of the Integration Application with the Relay Settings Repository application to obtain device locations for which settings are avaialble. Similarly, the Integration Application interfaces with the Short Circuit Software to obtain a list of potential device locations where settings may be modeled. An algorithm is then utilized within the application to match locational data from Relay Setting Repositories (device settings available for) to the Short Circuit Software (where devices can be modeled).

2) The device settings are imported into the Integration Application and interpreted to identify functional settings (such as distance reach), supporting element settings (instrument transformer ratios), and relay-specific logic statements (potentially trip masks for microprocessor-based devices).

3) With the availablilty of the device parameters and the location where it should be represented, the modeling of the devices in the short ciruict software can be conducted in an automated manner, assuming the short circuit software enables external manipulation of its data content.

4) Once the device and supporting elements have been modeled in the short circuit software, the relay settings can be imported to the model, either on a functional or tap basis (depending on the short circuit software in use).

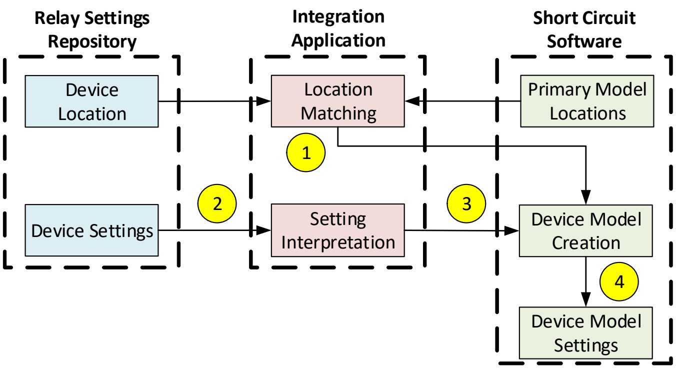

Fig. 2. Utilization of automation to enable modeling of secondary network elements

A similar version of this automated process can also be implemented to transfer primary model parameters from data repositories to the short circuit model.

This automated methodology of creating and updating primary and secondary system representation can ease the burden of maintaining simulation-ready models for PRC-027-1 evaluation. In addition, since data transfer is performed in an automated manner, potential issues related to manual transposition can be avoided.

IV. Fault current Comparison

Fault current comparison is relevant to Requirement R2 Option 2 of the PRC-027-1 standard and can be utilized to define the required BES elements that require protection coordination study. Use of this option requires the comparison of bus fault currents against an established baseline, with cases exhibiting 15% or greater deviation requiring coordination study. It should be noted that the bus fault current study, comparison, coordination study, and development of mitigation plan must be completed within individual bus-specific six-year periods.

This option can reduce the burden on utility engineers in evaluating PRC-027-1 through limiting the number of coordination studies to be performed but requires additional tracking and comparison mechanisms associated with the fault current comparison to be implemented and maintained.

A. Establishing and Maintaining Baseline Values

Baseline values are bus current magnitudes that are established to provide a control point for system configuration and conditions. Under PRC-027-1 requirements, coordination studies are required for BES elements associated with that bus should the system change sufficiently to cause a 15% or greater bus fault current. Baseline values must be established prior to the standard going into effect, which can be determined according to past records or through the execution of a new system-wide coordination study.

These baseline values can be updated in two manners:

- Upon installation of a new BES element
- Following execution of a protection coordination study

It should be noted that updating of baseline values must be done according to one of the above and cannot be changed at will to continuously keep fault currents under 15% deviation.

Recording and maintenance of the baseline value list can be achieved simply though use of spreadsheets listing bus identifying information, fault current value, and date of establishment, or can be stored within database applications or even short circuit software if supported. The medium used to record the baseline should be determined with consideration for integration with the fault studies and comparison tasks detailed below.

B. Performing Fault Current Studies and Comparison

The fault current studies can generally be executed using the built-in functions provided in industry-standard short circuit software platforms. Automation assistance may be utilized through employment of batch study options based on lists of applicable buses. This enables system-wide fault current studies to be performed as well as permitting fault current comparison to be executed for all applicable buses.

The comparison itself can be performed through a variety of means, including simple spreadsheet comparisons. However, utilization of more capable tools may bring several advantages related to tracking and coordination study preparation. Since the determination of required coordination studies is a direct result of the fault study, automated processes may be employed to generate the supporting lists required by the short circuit simulation software to identify which elements to conduct coordination studies on. Due to the fault comparison being based on buses, this automated tool would need to employ an algorithm to determine applicable BES elements associated with the bus in question.

One implementation of this process is shown in Fig. 3, with the specific tasks detailed numerically below.

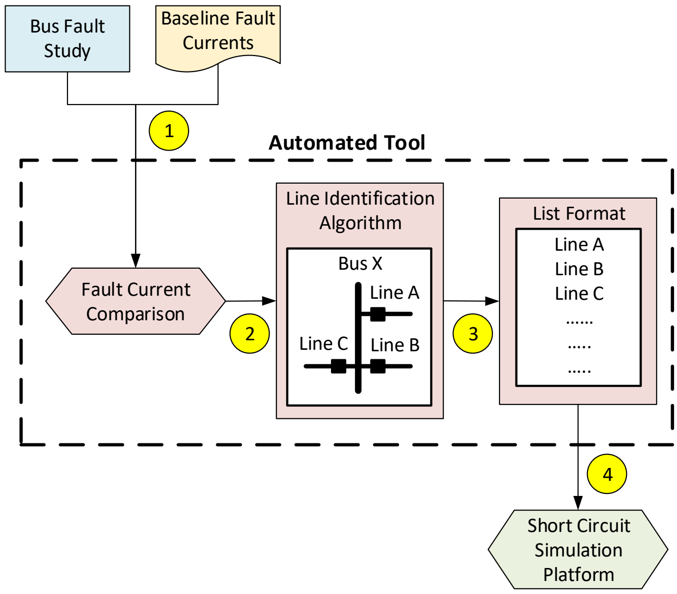

Fig. 3. Fault current comparison and identification of applicable lines requiring coordination study

1) Comparison of bus fault study values with baseline values for each applicable bus. There may be scenarios where a baseline exists but no matching present fault balue exists (in the case where a bus is no longer BES or has been removed), or where no matching baseline exists for a present fault value (new bus with no established baseline). Processes can be developed to handle these scenarios. The cases where present fault current deviates from baseline by 15% or more are identified in this comparison.

2) For those cases exhibiting 15% or greater fault current deviation, an algorithm is required to determine all BES elements connected to that bus. In the example shown, three lines are identified as being connected to bus in question.

3) If short circuit simulation software is to be used for the coordination studies, the list of lines that require study can be prepared and formatted by the automated tool.

4) This list can then be used with the short circuit simulation software performing the coordination studies.

This integration of tasks can reduce the effort burden on engineers performing PRC-027-1 compliance evaluation and reduce need for manual transferring of data and results.

C. Compliance Due Dates

Although fault current comparison can be performed with simple spreadsheets, the use of application tools can bring additional benefits to tracking considerations, including determination of compliance due dates. The PRC-027-1 standard requires that the entire process, including coordination study and development of mitigation plans (if required), be completed for each bus within individual six-year cycles. The compliance due date would be calculated based on the outcome of both present and previous fault current comparisons.

- If the deviation is less than 15%, no study is required, and PRC-027-1 compliance has been met for that bus for the next six years. The compliance due date would be the date of present study plus six years.
- If the deviation is greater than 15%, and the previous study was also greater than 15%, a new baseline value would have been established upon completion of the previous coordination study. The compliance due date would be the baseline establishment date plus six years.
- If the deviation is greater than 15%, and the baseline establishment date is older than the previous study date, two possibilities exist: the previous comparison did not require coordination study, or the required study and/or baseline update was not performed. The use of automated algorithms can look at fault comparison and baseline establishment history to determine the proper compliance due date for the present study.

V. Coordination Studies

Protection coordination studies can be performed in many different ways, and they depend upon the protection types (i.e. distance, overcurrent, communication assisted schemes, etc.) being used in the system, and the protection settings philosophy of a utility. As per PRC-027-1 the following protection functions are applicable for coordination review [1]:

- Distance protection, if infeed is used, or zero-sequence mutual coupling is used in determining reach settings
- Non-directional overcurrent protection
- Directional overcurrent protection, if used in a non-communication aided protection scheme
- Teleprotection schemes, differential protection, and fault detectors are **excluded** from the scope of coordination review

Any coordination analysis technique that can effectively evaluate coordination for the protection functions listed above, can be utilized. In this paper we are presenting the coordination analysis approach that is one of the most comprehensive methods for systematic protection coordination that can be automated using short circuit and protection simulation software applications. This approach is called Wide Area Protection Coordination (WAPC). In addition to satisfying PRC-027-1 requirements for coordination analysis in a systematic manner, WAPC also helps catch relay settings/design errors, which have been the highest cited contributing cause for misoperations in regions under NERC [3].

WAPC simulation for a BES element involves running a large set of fault scenarios, and evaluating protection coordination between adjacent protection systems, through simulating protection systems operation behavior in protection simulation software. The fault scenarios are created through a combination of the following variables:

- Fault Types: SLG, DLG, TPH, and LTL with zero or non-zero fault/arc impedance
- Fault Location: At set percentages across the length of a transmission line, terminals of a transformer, and buses
- Network Contingencies: Local and remote source outages, terminal outages, and mutually coupled line outages
- Protection System Contingencies: protection package outages, and communication assisted scheme outages

Typical WAPC study for a transmission line may involve on average 800 fault scenarios. For each fault scenario, the simulation software goes through the sequence of breaker events until the fault is cleared. At each breaker event the network fault current is re-calculated and protection operation behavior is re-assessed. Such an analysis provides comprehensive assessment of protection coordination, which would otherwise be very tedious to preform through traditional methods. The sequence of events report for a WAPC study is structured as shown in Fig. 4.

WAPC Simulation Output with N Fault Scenarios		
Fault Scenario 1	Event 1	: Fault Applied Report operation time for all protection elements in the simulation area, flag any coordination issues
	Event 2	: Breaker Opened Report operation time for all protection elements in the simulation area, flag any coordination issues
	•••	
	Last Event	: Breaker Opened Fault is either cleared, or all protection devices have dropped out
Fault Scenario 2		
•••		
Fault Scenario N		

Fig. 4. WAPC Simulation Output Format

VI. Analyze Coordination Results and Document Mitigation Plan

The WAPC approach allows us to systematically evaluate coordination by simulating a large set of fault scenarios, however, the trade-off is that the output is very detailed and overwhelming for a human to review. Therefore, the additional step of automated processing and analysis of the output becomes very important. The main objective of this step is to re-organize and condense the simulation results into a summary report that can be reviewed by protection engineers easily. The sequence of events report created during a simulation presents issues in association with each fault scenario, however, protection engineers are interested in seeing the coordination issues summarized by each miscoordinating protective device. Besides, listing miscoordinating protective devices, the processed WAPC summary report for a BES element must also present details that assist in the review process such as graphical representation of miscoordinations, risk associated with miscoordination, provision to record mitigation plan, etc. It is clear that there are many possible ways to create this report, and the design of it must be an important consideration when creating a compliance process using the WAPC approach.

The processed simulation results, documented in a WAPC summary report, need to be reviewed by protection engineers. The outcome of the review is a mitigation plan designed to resolve the coordination issues. In order to facilitate automation of compliance reporting, the process of documenting the mitigation plan shall be standardized. Providing standard mitigation action categories, such as, Setting Change Required, Protection Upgrade Required, No Action Required, etc., and providing specific fields in the WAPC summary report to record the mitigation plan actions, can allow reliable automated reporting of WAPC study results for a large set of BES elements.

VII. Data Management and Reporting

Data management and reporting is an important aspect for any compliance process. Properly managed data does not only support the compliance process, but also support automated production of audit-ready reports showing proof of compliance. Since, PRC-027-1 compliance process involves a number of steps, it is recommended that a central file management system or a database, layered with a capability to manage workflow should be utilized to manage the data and processes for system modeling and coordination study effectively.

The approach described in this paper, especially related to performing fault current comparisons and coordination studies, is designed to facilitate data management. Standardizing study output formats, utilizing unified naming conventions, connecting directly to short circuit software platform, and implementing processes for gathering engineering feedback, provides all the necessary information for a software application to generate audit-ready compliance evidence reports.

VIII. Fault Comparision Approach vs System-wide Coordination Studies

As described earlier, PRC-027-1 provides 2 fundamentally different approaches for demonstrating compliance for requirement R2 i.e. fault current comparison approach and system-wide coordination studies. The suitability of an option for a utility depends upon the following factors:

A. Expected Fault Level Change in the Network

The fault current comparison approach (option 2) is designed to reduce the effort for coordination analysis for utilities whose system's fault levels may not experience substantial change over a six-year period. However, this comes at the added cost of maintaining a fault level baseline and performing fault current comparison checks. For a given compliance cycle, based on fault comparison results, utilities may need to perform only a small number of coordination studies, and can scale the protection modeling and verification activities accordingly. However, if a large number of buses register greater than 15% fault current deviation from the baseline, then it may warrant a large number of coordination studies to be performed. Therefore, benefits of fault current comparison approach will diminish relative to system-wide coordination study.

B. Effort Required to Perform Coordination Analysis

The effort required to perform coordination analysis varies by the type of protection elements being used in the system, as well as the protection settings philosophy of a utility. Therefore, utilities whose protection system consists of higher percentage of communication assisted protection schemes, and lower percentage of overcurrent-based protection, may experience lower effort to perform coordination analysis, and therefore, prefer a system-wide coordination approach.

C. Utilizing Other Benefits of System-wide Coordination Studies

WAPC coordination study can help catch protection settings/design errors, therefore, reducing risk of misoperations. Performing a system-wide coordination study can provide utilities higher confidence in their protection system's reliability. Furthermore, system-wide coordination study requires complete primary network and protection model validation, which can be useful in automating other compliance studies, such as PRC-023, and PRC-026. Based on specific needs of a utility, these additional benefits may help justify the effort for system-wide coordination studies.

IX. Conclusion

This paper has presented one potential approach to meeting PRC-027-1 compliance requirements as well as the technical and logistical considerations in performing the evaluation studies. Through advancements in power system and protection settings data management, protection simulation software platforms, and the software processes to integrate and operate these applications, the burdens of PRC-027-1 evaluation process can be mitigated greatly through software-based automation.

Throughout the entire evaluation process, automation tools can be utilized to reduce manual effort in repetitive and data transposition tasks, enabling engineers to focus more on the technical aspects. Automated processes can be developed to assist engineers in most of the major tasks of PRC-027-1 compliance.

The approach that is presented in this paper is vendor independent and has application possibilities to both fault current comparison and system-wide coordination study options of PRC-027-1. The factors that may influence a utilities decision on selecting a particular option are described in the paper.

Although the discussion in this paper is specific to PRC-027-1, the implementation of the technical and logistical elements, such as integrated data sources and automated processes, to support compliance evaluation can provide wide-ranging benefits in other areas. These can range from greater integrated relay settings development support to provision of system operating limits such as maximum loading due to protection settings.

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BIOGRAPHIES

Ishwarjot Anand is an Advisor in the Protection and Control team, at Quanta Technology, Markham, Canada. He has a BASc in Mechatronics and Robotics Engineering from University of Toronto, Canada. He has expertise in computer-aided modeling and analysis of electrical power systems and protection systems for both transmission and distribution networks. He has led several protection engineering automation and data management projects, including automation for NERC PRC Standards Compliance. He has worked on large-scale wide-area protection coordination studies for AltaLink, Xcel Energy, and National Grid Saudi Arabia. He has also worked on renewable integration and automation projects.

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