NERC PRC-005 Compliance Made Easy with Digital Substations

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Abstract - NERC PRC-005 standard outlines the minimum maintenance requirements which must be met for protection systems, equipment used for automatic reclosing and sudden pressure relaying by transmission owners, generator owners and distribution providers. This standard defines the minimum set of tasks which must be performed within a maximum time interval. Non-compliance with the standard can result in severe monetary penalties and damage the reputation of a utility. Most utilities do have maintenance programs for their protection systems but PRC-005 has increased the burden by creating a need for additional activities and documentation which is used to ensure compliance to the standard. Most of the copper wiring in a traditional substation is not monitored and requires testing at accelerated intervals requiring additional resources and require equipment or protection system outages. The maintenance intervals in the standard can also necessitate multiple visits to a substation resulting in sub-optimal maintenance programs from an asset management perspective. Typically, utilities do not have a reliable inventory of auxiliary relays, used for tripping and lockout, which further increases the complexity in complying with PRC-005 requirements.

Digital substations, with the use of IEC 61850 standard, reduce design, installation, testing and commissioning costs. They also result in a system which is monitored from primary equipment to the secondary systems. Primary equipment such as fiber optic current sensors can digitize the information at the measurement location, thereby, negating the need for any copper wiring. Even if information cannot be digitized at the measurement location, use of stand-alone merging units to publish sampled values via process bus (IEC 61850-9-2LE) can significantly reduce the amount of unmonitored copper wiring. The use of station bus (IEC 61850-8-1) decreases the wiring within the control building which can further reduce the tasks which need to be performed during maintenance. Data available on process bus and station bus can be used to automate maintenance tasks. It also allows for the elimination of some auxiliary relays while still meeting the functional requirements for their application. PRC-005 also requires testing of alarm paths which can be continuously monitored with IEC 61850 instead of testing the hard-wired contacts.

This paper investigates how digital substations can reduce or eliminate the maintenance tasks that are required to be completed as part of PRC-005. AltaLink commissioned their first digital substation in 2018. It presents AltaLink’s perspective on achieving PRC-005 compliance using digital substation technologies. It discusses approaches currently in place and those under consideration. Reduction of maintenance costs while providing a reliable system is the goal of every asset management program and digital substations are an excellent tool for achieving that goal.
1 Nomenclature
A/D Analog-to-Digital
AESO Alberta Electric System Operator
BCU Bay Control Unit
BES Bulk Electric System
CT Current Transformer
GOOSE Generic Object Oriented Substation Event
IED Intelligent Electronic Device
ISO Independent System Operator
LAN Local Area Network
MMS Manufacturing Message Specification
NERC North American Electric Reliability Corporation
PIU Process Interface Unit
PRP Parallel Redundancy Protocol
VT Voltage Transformer
RIO Remote Input Output
RTU Remote Terminal Unit
SCADA Supervisory Control and Data Acquisition
SV Sampled Values
UFLS Under Frequency Load Shedding
UVLS Under Voltage Load Shed

2 Background
AltaLink is an investor owned transmission company and is Canada’s first independent transmission provider. It serves over 212,000 square kilometer territory with more than three million customers constituting 85% of Alberta’s population.

AltaLink owns and operates over 315 substations and over 13,000 kilometers of transmission lines at 69kV, 138kV, 240kV and 500kV levels. There are three interties with the neighboring provinces.

In Alberta AESO, which is the provincial ISO, has released reliability standard PRC-005-AB1-6 to set minimum requirements for documenting and implementing programs for maintenance of protection systems, automatic reclosing and sudden pressure relaying affecting reliability of transmission systems. Majority of the standard is well aligned with NERC’s PRC-005-6. The standard will become effective on October 01, 2019. For simplicity and for the context of this document, rest of the document refers to PRC-005.

PRC-005 requirements will impact AltaLink’s maintenance standards, practices and procedures in terms of equipment being maintained, maintenance activities, intervals and documentation.

Digitizing the substation could reduce cost, time and effort associated with these maintenance aspects.
3 Maintenance Practices

AltaLink has always followed time-based maintenance approach, considering technology class (for e.g. numeric, electromechanical, discrete or integrated) and criticality of the substation in the power system in determining maintenance intervals for certain components. There is also provision to readjust maintenance cycle based on preventative/corrective maintenance performed since the last periodic maintenance.

Following sections provide an overview of some selective existing practices related to maintenance aspects that are impacted by PRC-005.

3.1 Equipment and Maintenance Intervals

PRC-005 has increased the number of equipment to be maintained and in some cases maintenance intervals are to be modified.

As an example, the distributed UFLS and UVLS systems that are not part of the BES are periodically maintained only if they meet criticality threshold set based on their location in the power system. Per PRC-005 requirements, all the UFLS and UVLS systems are to be maintained at a minimum interval of 6 or 12 years depending if they are monitored.

Another example is circuit breaker trip coil maintenance interval, which is conventionally tied with the circuit breaker maintenance. The maintenance cycle is based on time elapsed and the operation count since last maintenance. There are three sets of limits for three categories in which breakers are classified based on their vintage and design. A breaker is scheduled for maintenance when it exceeds either of these predefined limits, whichever comes first. Presently, for high voltage breakers, the maintenance cycle could be up to 10 years long. Per PRC-005 requirements, breaker trip coils are to be maintained at a minimum interval of 6 or 12 years depending if they are monitored.

3.2 Maintenance Testing and Activities

Maintenance testing is essential to ensure that protection systems and their components are working as intended. Numerical devices have built in self-monitoring, which monitors the device for failure in its digital circuits and issues alarms. However, the numerical devices do have some components that may not be monitored. For example, parts of A/D converter, input and output contacts. These components require testing at regular time intervals. The conventional instrument transformers (CTs and VTs) are hardwired from their location in the yard to IEDs in the control building. Unless the relays have CT and VT failure detection functions and are enabled, the availability of reliable current and/or voltage inputs is not warranted and may lead to unexpected results.

In essence, the purpose of relay maintenance testing is to prove that wiring from conventional instrument transformers to tested relay is intact, the relay is measuring analog quantities within accuracy limits, and relay’s input and output contacts are working properly.

As is the case with conventional testing, the process is accomplished in number of steps by field technicians present on site. At high level, the test zone is established and is isolated by disconnecting analog inputs to the relay from instrument transformers and by isolating relays binary inputs and outputs via the test switches. For safety, current transformer secondaries are shorted. Current and/or voltage outputs from the test-set are physically hardwired to the test device via test switches. For imitating protected asset status and monitoring operation of the relay
functions, input and output contacts from test-set are also hardwired to the relay input and output contacts.

The accuracy of relay A/D converter is checked by comparing current and voltage signals measured by the relay with another device that is connected to same CTs and VTs. If another comparable numerical device is not available, portable current and voltage meters are used for comparing measurements. Usually, the measurements and their comparison is performed manually. There could be time lapse between pictures of the different IEDs which are being compared which could potentially skew the results.

In AltaLink protection systems, majority of alarms issued by the protection relays are hardwired to the RTU. In addition, any status signal exchange or triggers between the relays are also hardwired. Relay input and output contacts are tested by changing input status to the relay and operating relay functional elements related to the output contacts.

Same process is repeated for each device being tested. This involves moving test-set around the control building; connecting and disconnecting hardwiring between test-set and the tested devices. Significant time and effort goes into this exercise and ensuring that test zone is properly isolated so that test activities do not result in any inadvertent action.

Note that successful testing proves that relay’s functional aspects are working at the time of testing. Any subsequent failures of the unmonitored components could result in an unexpected operation or may remain unnoticed till the next maintenance cycle.

PRC-005 recognizes the benefit of continuous monitoring and has extended maintenance intervals for monitored components and circuits.

3.3 Documentation

PRC-005 requirements are driving modifications in integration between maintenance planning, management and test databases. The emphasis on detailed documentation of tests and results has also increased.

Maintenance of protection systems and circuit breaker trip coils are performed by two different field groups; and test details and results are stored in different databases. The enterprise system used for managing maintenance intervals does not have all the equipment inventory and maintenance information required for producing reports to prove compliance for the new requirements. Modifications are required in these database systems to increase integration of details required for reporting purpose and at the same time improving maintenance cycle management. A few maintenance requirements that now require documentation or have increased documentation requirements are mentioned here.

Conventionally, AltaLink has not maintained an inventory of auxiliary, including voltage sensing devices for auto-reclosing, and lockout relays. And for this reason, independent test records are not maintained.

The trip circuits are maintained at defined intervals, but the test activities and results are not documented in detail.

With advancement in technology and change in philosophy, auto-reclosing implementation practice has changed i.e. from discrete auto-reclosers to auto-reclosing function in line protection relays and now in breaker controller relays. When auto-recloser is not a discrete device, their
maintenance cycle is tied to the relay in which the function is implemented. In such cases, autorecloser test activities and results are not separately tracked and documented.

4 Digital Substation

AltaLink like many utilities of its size has conventionally followed a set of strict substation P&C design standards that are very seldom deviated from. The advantages of doing so are for the obvious reasons of achieving higher engineering efficiency and consistency with easier quality control and work administration. Figure 2 provides example of a typical 138 KV bay with redundant protections, a bus-bar protection, a breaker controller, and a centralized RTU for monitoring and control operations. All inter-device connections are made via conventional copper wires including the path between the relays and the RTU. This conventional approach results in labour intensive installation and troubleshooting experience and lack of visibility to the integrity of underlying networks.

The target project site was a 138KV switching station (Blackie) with no local transformer loads, consisting of a simple bus bar connecting three transmission lines and one capacitor bank. Figure 3 provides the SLD for illustration purposes.

Alberta ISO Rule 502.3 [5] outlines protection system redundancy requirements from measuring transformers to trip circuits and mandates that protective relays be sourced from different manufacturers. For a digital P&C system, the A/D conversion and digital signal processing function of a protective relay are now separated from the main application processing core and performed in the PIU with trip command execution taking place in the RIO units, all of which are interconnected by networking equipment to form a digital protection system. It’s therefore plausible to draw the analogy that all integral parts of a digital automation system must also meet the ISO 502.3 redundancy requirements.

Two main process bus technologies were chosen by AltaLink for Blackie digital substation pilot – LAN based and a point-to-point concept. AltaLink ended up qualifying two vendors carrying these two distinct technologies to supply for the project. Figure 4 below displays the new process bus SLD of a line bay that employs the two different technologies. The LAN based system requires ethernet switches resulting in additional points of failure in the protection system. PRP was applied to improve dependability by ensuring lossless data transfer upon any failure in the substation LAN. Because of the incongruent nature of the two vendor technologies, merging units and protection relays were only paired from the same supplier, making them two fully independent systems from the measurement perspective.
5 Benefits of digital substation

Although all the concepts described below have not yet been implemented by AltaLink, it is believed that they would significantly reduce the burden associated with PRC-005 compliance once digital substations are more widely deployed in the AltaLink system.

5.1 Instrument transformer testing

To ensure proper operation of the A/D converter of the relay or the merging unit would, typically, require a comparison of metering values on the front panel of the relay while the protective relays are in service or injection of analog values from a test set [1]. These tasks require P&C technicians to travel to site which increases operational expenses. It also places the onus on technicians to ensure that correct documentation is created to ensure compliance to PRC-005. With the availability of SVs via IEC 61850 9-2LE [7], values can be published from ‘A’ and ‘B’ protection systems, via analog GOOSE, to an independent IED such as an RTU. The analog values can then be compared continuously, and alarms can be generated based on the difference beyond a certain threshold. The flexibility of a digital substation also allows this approach to be applied if ‘A’ and ‘B’ protection systems are wired to the same CT core and PT secondary. SVs from an IED subscribing to data from a different CT core and PT secondary can also be used for online comparison.
The concept described above should meet the requirements of PRC-005, thereby, resulting in no periodic maintenance required. Non-conventional instrument transformers, based on fiber optics, eliminate all the copper wiring associated with CTs and VTs. In addition to being safer compared to conventional instrument transformers, the use of fiber optics means that the entire measurement path is continuously monitored which further supports PRC-005 compliance.

5.2 Lockout relays
AltaLink’s conventional design for lockout requires the lockout relay to be implemented in the protection module which requires a protection function to result in a lockout. Also, AltaLink does not use lockout relays in the trip path. The normally-closed (NC) contact of the lockout relays is used in the close circuit to prevent the breaker close if the lockout has not been manually reset.

Conventional electro-mechanical lockout (86) relays [6] were eliminated and a digital approach using IED programmable logic to achieve a similar lockout procedure was developed in this pilot project. Trips in the protection IEDs shall be latched and the status published to corresponding RIOs. Primary lockout reset is done via programmable push button(s) on the protection IEDs under normal conditions to mimic the conventional protection panel reset buttons. The logic to latch the lockout needs to be duplicated in the RIOs to seal-in the various protection lockouts in case the protection IED which initiated the lockout fails or goes offline, thereby, resetting its lockout signal on the network. The latch in the RIO would automatically reset once the originating protection lockout resets or it can also be reset via another programmable push button in the RIO if the originating protection IED fails. The programmable push button in the RIO is only meant to be used if the lockout cannot be reset via the original protection IED.
Implementation of the lockout logic in the protection IEDs and the RIOs resulted in the elimination of electro-mechanical lockout relays. Even though AltaLink does not use lockout relays in the trip path, this concept nullifies all the requirements which require testing of electro-mechanical lockout devices and eliminates the need to create and maintain an inventory of the lockout relays. Once the logic has been commissioned, confirmation that it has not been changed can be achieved by performing a settings comparison against the approved settings in the database.

5.3 Trip coils or actuators of interrupting devices
AltaLink’s standard apparatus control scheme uses the RTU (remote SCADA or integrated HMI) as the primary control authority and a mechanical control handle located on the breaker controller panel as the standby option. For breakers with 2 trip coils, TC1 and TC2, the trip signal from the RTU or the control handle is wired only to TC1. Verification of the ability of TC1 to operate the breaker can be completed via remote SCADA control. AltaLink would have to send field staff to site to verify operation of the breaker via TC2. Verification of the ability of the CC to operate the breaker will be performed after the breaker has been opened via TC1.

To maintain a similar failsafe control philosophy without the control handles, a hot-standby algorithm based on hardware and communication availability was implemented in the RTU. The BCU was chosen as the primary control proxy through which the IEC61850 client-server secure control service would be driven. The RIO (B) would act as the backup channel in case of BCU failure. A pushbutton on the bay controller was also programmed as emergency backup in case of RTU failure. This way all the potential failure modes were covered. This design concept resulted in the implementation of the control signal to both the trip coils. Access to both the trip coils can
be used to issue a control command to each trip coil individually which would meet the requirement to verify the operation of the breaker via each trip coil.

5.4 Monitoring of control circuitry
PRC-005 requires all unmonitored control circuitry associated with protective functions to be verified every 12 years. This would require the circuitry from each relay needs to be verified to ensure its integrity which can be a time-consuming process. AltaLink has, typically, verified the operation of protective relay output contacts during relay maintenance and relied on the trip coil monitoring to ensure that the integrity of the trip circuit is maintained. The normally-open (NO) contacts of the auxiliary relays which are used to pass the trip signal to the trip coil also need to be tested [4].

The use of process bus and station bus allows for continuous monitoring of the communication ability between the relay and the RIO which eliminates the need for testing associated with control circuitry between the relay and RIO [4]. It also removes the need for any auxiliary relays to be installed since trip signals are distributed to all the breaker(s) trip coils via station bus or process bus depending on the architecture. The conventional design required multiple control circuits, one from each protection relay, to be wired. The use of GOOSE messaging to trip the circuit breaker(s) also results in consolidation of all the control circuits further reducing the control circuitry that needs to be tested. Only the output contacts of the RIO need to be wired to the trip coils. The integrity of this control circuitry and operation of relay outputs that are essential to proper functioning of the protection system are also verified during the testing to verify that each trip coil can operate the circuit breaker. Since signal exchange between IEDs is performed via GOOSE in a digital substation, these signals are also continuously monitored, further minimizing the requirements for verifying unmonitored relay inputs and outputs. The same is also true for control signals to the close coil of the breaker.

5.5 Alarm path monitoring
As described in section 3.2, AltaLink has historically hardwired the alarms from relays to the RTU. This would result in a large number of alarm paths which would have to be tested to verify that the alarm path conveys alarm signals to a location where corrective action can be initiated to ensure compliance with PRC-005. AltaLink operates an around the clock control center to monitor the transmission system. All critical alarms are reported to the control center where corrective action can be initiated within 24 hours.

The use of station bus to transfer alarms, via MMS, would significantly reduce the effort required to test for all alarm paths since they would be continuously monitored. This would also ensure compliance to PRC-005.
5.6 Documentation
AltaLink is planning on using multiple drawings to prove that all sections of the control circuitry are tested within the timeframes required by PRC-005 resulting in addition of significant burden from a documentation perspective. They have also not created and maintained an inventory of auxiliary relays used in the trip path.

Automatic monitoring afforded by the technologies used within the digital substation will result in the creation of logs which can be used for PRC-005 compliance. The documentation would be produced by online comparison of SVs from instrument transformers and monitoring of the LAN used for process bus and station bus. Verification of the ability of the breaker trip coils and close coils to operate the circuit breaker would not only provide documentation for that requirement but also for the verification of the control circuitry from the RIO to the trip coil.

6 Conclusions
The paper describes AltaLink’s maintenance standards and practices which have, conventionally, been based on a time-based maintenance program. It also discusses the increased effort required to ensure compliance with PRC-005, especially with regards to maintenance activities and documentation. Additional activities for creating and managing inventory of auxiliary relays are also required. PRC-005 will be effective in Alberta on October 1, 2019.

AltaLink designed, engineered, tested and commissioned their first digital substation in November 2018. It was a significant achievement since it resulted in a leap from a highly standardized copper wiring-based design to a fully digital protection and control system. The paper describes how digital substations can be used to reduce the burden associated with PRC-005 compliance. Implementation of process bus and station bus to broadcast SVs and GOOSE allows for continuous monitoring of critical portions of the protection and control system whose integrity is the focus of PRC-005. By reducing the number of unmonitored control circuits and auxiliary relays, via the use of station bus, the requirements for creation of an inventory and subsequent testing are also diminished. Consolidation of trip and close signals to the breaker via RIO not only reduces the number of control circuits that need to be tested but also lends itself to consolidation of verification tasks required for PRC-005 compliance. Availability of data on the local area network allows for maintenance to evolve from time-based to event-based programs by performing online comparisons from different sources. The implementation of continuous monitoring can also reduce the burden required to generate adequate documentation for compliance.

7 References


8 Biography

Harjinder Sidhu is Principal Engineer for Protection and Control at AltaLink in Calgary. His role is to develop and maintain philosophy for engineering and design of protection systems for safe, economic and reliable operation of the power system. He joined AltaLink in 2007 and has held varieties of diverse roles including Engineering Manager, Protection and Control Engineer, Project Engineer and Project Manager. Prior to joining AltaLink, he worked as Technical Specialist at General Electric for three years. He received Master of Science Degree in Power System Protection from the University of Saskatchewan. As a Research Assistant, he investigated application of traveling waves for accurate estimation of location of faults on transmission lines. He is registered as a Professional Engineer in the province of Alberta and is a member of the IEEE Power and Energy Society.

Varun Chhibbar joined ABB in Calgary as the Regional Sales Manager for Grid Automation in November 2018. He is responsible for the ABB’s Grid Automation portfolio of Protection and Control, SCADA and Telecommunications for Western Canada. Prior to joining ABB, Varun was working as the owner’s engineer for delivery of Control and Protection system for Labrador-Island Link HVDC project. Before working on the HVDC project, Varun was with AltaLink for over 11 years where he last held the position of Principal Engineer for Protection & Control. Varun graduated from the University of Saskatchewan with B. Sc. in Electrical Engineering in 2006. Varun is a registered as a Professional Engineer in the province of Alberta, Canada and is a member of the IEEE Power and Energy Society.

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