Simplifying Compliance: An Integrated Approach to Meeting NERC PRC-002 and PRC-005 Requirements

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***Abstract*—NERC PRC-005 requires the establishment of a protection system maintenance program (PSMP) to verify that the critical components of a protection system are operational and to restore components that are faulty. PRC-005 overlaps with PRC-002 for verification of protection control circuits that include protection devices, communications channels, and primary equipment. For qualifying substations, PRC-005 and PRC-002 both require oscillography, dynamic disturbance, and sequence of events (SOE) data. These requirements cast a burdensome task on organizations to collect, archive, and analyze data from numerous sources to properly maintain critical assets in a power system.**

Fortunately, the presence of advanced microprocessor-based devices in modern protection schemes provides ample opportunity to automate many of the processes required for a PSMP and PRC-002. Machine processing of oscillography, dynamic disturbance data, and SOE data for steady-state and transient conditions provides the basis of an automated PSMP. This paper proposes schemes for integrating the PRC-005 and PRC-002 data requirements to enhance a PSMP. The paper also includes several examples of automated processes that capitalize on these schemes to provide real-time analysis of asset performance.

I. Introduction

Under the direction of the U.S. Federal Energy Regulatory Commission, the North American Electric Reliability Corporation (NERC) was designated as the Electric Reliability Organization on July 20, 2006. From this date on, NERC has been responsible for improving the reliability of the North American bulk electric system (BES). To achieve this goal, the development, implementation, and subsequent enforcement of a reliability standard has been the primary responsibility of NERC. BES asset owners are obliged to comply with the various requirements in the standards if the equipment they own and/or operate falls within the inclusion criteria defined in the standards. Failure to comply with the standards can result in significant monetary fines.

This paper highlights functional overlap between the data sets required by NERC PRC-002 and PRC-005 standards and how these data can enhance power system maintenance programs. While specific versions of these standards are called out in detail, it is not the intent to focus on the version or examine the changes between enforced or draft versions. The following purpose statements for each standard provide insight into the larger value of data in improving the reliability of power systems:

> To document and implement programs for the maintenance of all Protection Systems, Automatic Reclosing, and Sudden Pressure Relaying affecting the reliability of the Bulk Electric System (BES) so that they are kept in working order. – PRC-005-6 [1]

> To have adequate data available to facilitate analysis of Bulk Electric System (BES) Disturbances. – PRC-002-2 [2]

The inclusion of an asset in the criteria of one standard does not mean that the same asset is included in the other. However, while the standards provide a minimum set of devices to achieve the desired BES reliability targets, the data, both implicitly and explicitly called out, are valuable for increasing many operational metrics that are important to electric utility businesses as well to many other utilities and industrials. A comprehensive strategy to extract the diverse data from infrastructure and a clear plan on how to process the data for value-added outcomes is necessary to improve reliability and to return increased value to the many stakeholders of the electric power system.

II. PRC-002 Overview

The PRC-002 standard specifies the following three general types of data that must be reported to the regional Planning and Reliability Coordinator:

1. Sequential events recordings (SER) for circuit breaker positions.
2. Fault recording (FR) of high-resolution electric quantities with conditions on minimum recording rate and duration.
3. Dynamic disturbance recording (DDR) defined by continuous recording of low-resolution data with a minimum rate and retention period.

SER provides state information for breakers. FR data are oscillographic snapshots of electrical quantities on designated buses. The DDR data are critical for the analysis of wide-area impact disturbances. Together these data provide the information required for forensic analysis of significant BES disturbances.

III. PRC-005 Overview

Compliance with NERC PRC-005 entails the creation of a comprehensive protection system maintenance program (PSMP). The standard defines devices and equipment operating in protection systems that require a documented maintenance plan. The list includes communications systems, voltage- and current-sensing devices, control circuitry, automated reclosers, sudden pressure relays, and station dc supplies associated with protection functions. Execution of the PSMP has traditionally been based on fixed time intervals, where regulated assets are taken out of service for routine maintenance. Given the number of devices installed in a utility's territory, this is a costly drain on operational budgets and of employee time.

NERC PRC-005-6 allows extension of maximum maintenance intervals for some group of devices when continuous monitoring methods are employed. The standard also allows for performance-based maintenance plans where maintenance intervals are set on the performance of a subset of devices. Guidelines for establishing and maintaining technical justification for performance-based maintenance can be found in Attachment A of PRC-005-6. Both time- and performance-based maintenance can be used in the overall PSMP. Extending the maintenance interval can have dramatic impact on operational expenses.

IV. Integrated Data Collection System

An automated system can be constructed to monitor data in real time, provide verification of device configurations, and translate those data to standard reports for power system components regulated under NERC standards. This system leverages the vast and diverse sets of data from modern and legacy substation devices and provides the following benefits:

- Improves awareness of device and equipment health.
- Identifies potential latent maintenance conditions that may be present in the interval between maintenance check.
- Collects disturbance data that can be used for analysis and for control circuitry validation.
- Supports maintenance and testing documentation for internal process validation and compliance audits.

The problem emerges in the form of overhead operational costs required to stay compliant with these standards. NERC PRC-002 and PRC-005 standards differ significantly in their objectives, but both rely on the collection of data from the myriad of devices capable of reporting digital data. Awareness of any potential overlap between required data sets can assist an organization in reducing operational cost by leveraging one compliance scheme as a source of data for the other. This overlap is especially important when compliance efforts for each individual standard are being managed by independent groups within an organization where data sharing between groups is generally minimal.

A variety of infrastructures and schemes can be used to collect the data necessary for compliance or operational efficiency improvements. Fig. 1 outlines the equipment, functions, and services required to extract value out of the data in a substation or industrial environment. Many organizations will likely have some or most of the components needed for an automated collection scheme, while others will need to build upon layers as needed to start extracting the data from the primary sources that impact the stability and reliability of electric power systems.

The following sections outline several use-cases that leverage PRC-002 data sets and edge processing techniques to develop asset maintenance indicators that meet and exceed PRC-005.

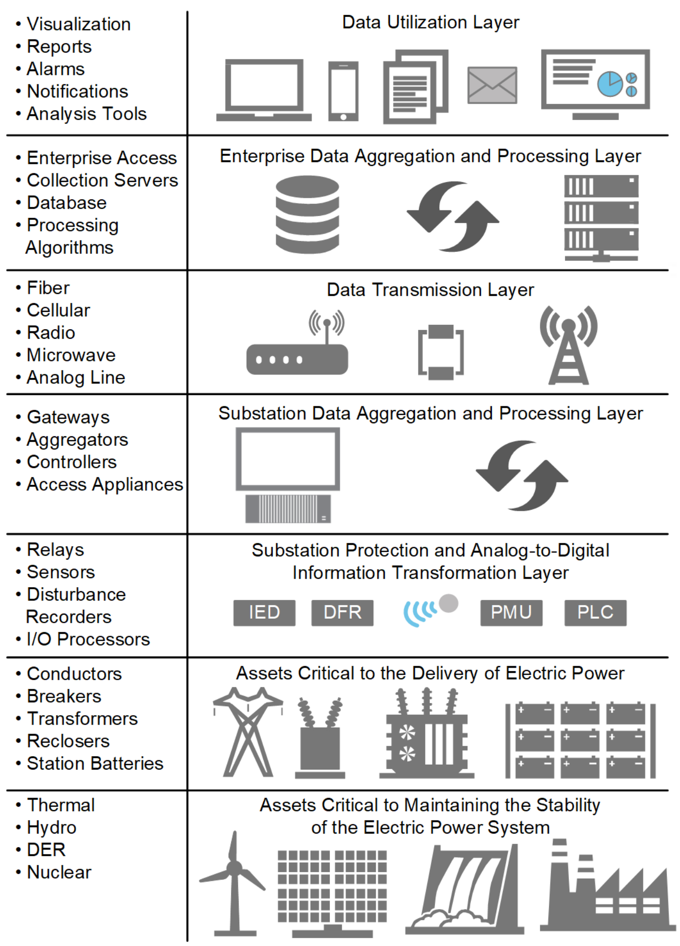

Fig. 1. Required Equipment, Functions, and Services

V. PT/CT and Relay Data Processing Monitoring

NERC PRC-002-2 requirements R6 through R11 identify the monitored assets and data collection methods for DDR data [1]. DDR data are generally presented as streamed data from the measurement device to a data recording appliance to support the minimum requirement of 30 messages recorded per second. R6.3 requires the measurement of three-phase real and reactive power or the necessary phase voltage and current measurements to calculate the power quantities. NERC PRC-005-6 Table 1-3 specifies that for a cross-section of a given system, voltage and current sensing devices (potential transformers (PTs) and current transformers (CTs)) require no periodic maintenance if a monitoring system is implemented that performs continuous comparison of measurements against an independent measurement source and provides alarms for excessive error or failure [2].

Redundancy in PT/CT placement and associated measurement systems is a common technique used to maximize protection system reliability and data availability for monitoring [3].

A data aggregation appliance that collects streaming voltage and currents transduced by redundant PTs/CTs and measured by associated intelligent electronic devices (IEDs) can act as a single source of both archived data sets and asset health information for PRC-002 DDR and PRC-005 PT/CT monitoring requirements. When the appliance includes an IEC 61131-3 logic engine [4], such a system can be programmed directly by the compliance engineer.

The following example discusses how a combined DDR collection and PT/CT monitoring system can be implemented in a generic edge processor (EP).

Fig. 2 depicts a redundant PT/CT monitoring scheme.

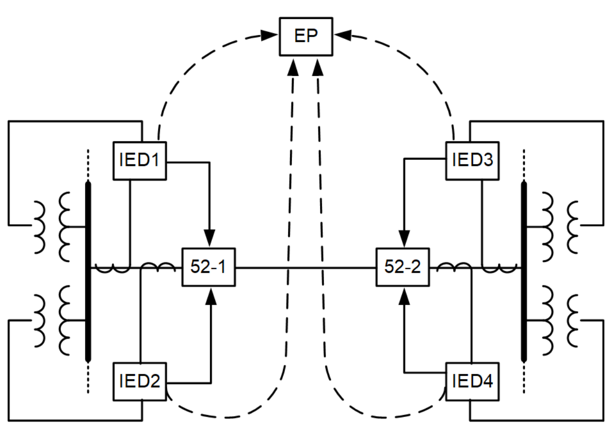

Fig. 2. Redundant PT/CT Topology

In Fig. 2, four CTs measure current from the same line and two sets of PTs measure the voltage of two buses. Each microprocessor-based relay (IED1 through IED4) collects three-phase voltages and currents from a single CT and PT and transmits those measurements to a substation-level EP.

Fig. 3 shows an example arrangement of functions within the EP. These functions operate in parallel on the incoming current and voltage measurements to produce data and information applicable to both PRC-005 and PRC-002. These functions are described as follows.

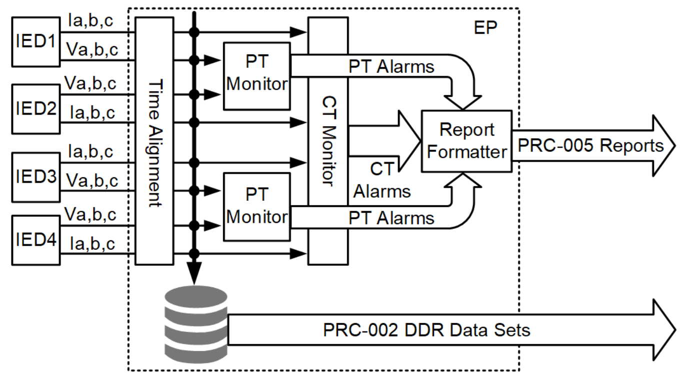

Fig. 3. Example PT/CT Monitoring System

A. *Relative Excursion Monitoring (PT/CT Monitor)*

A generic channel difference monitoring block can be applied to any group of channels that present redundant measurements. Such a block allows user specification of a reference measurement (useful when only two redundant measurements are available). When more than two redundant measurements are present (such as this example, with four CTs), a relative comparison can be made between all redundant channels to identify the failing CT or PT. Such a function can be programmed with warning and alarm thresholds, settable as a percentage deviation from the reference as well as associated pickup-time durations. Such a function can provide a structured output, containing a Boolean status for alarming, time stamp of Boolean assertion, and quality information [5].

B. *Time Alignment*

To qualify incoming samples for relative comparison, a time-alignment mechanism should be implemented that can provide the subsequent functions with guaranteed time-coherence of delivered samples. A time-alignment function generally waits a specified duration to collect samples with similar time stamps from multiple sources and delivers a sample set with a single time stamp. Such a function should provide time-aligned data sets that satisfy the following conditions:

- The original time stamps of the samples that make up the sample set vary from each other by no more than a specified maximum.
- The samples that make up the sample set arrived at the EP within a specified maximum duration relative to each other.

C. *Report Formatter*

User-specification of end-report format allows the responsible entity to maximize the ratio between actionable and non-useful information. An EP that employs a file system and associated functions for file writing/reading can easily be programmed to generate reports that represent a snapshot of the current system status and contain only the information relevant to the entity. This may include PT/CT alarm status, EP, and protective relay self-diagnostics, plus any other element accessible to that EP.

The set of functions proposed in this example represents several considerations of a PT/CT monitoring system. A more comprehensive system may apply additional qualification to the incoming data channels and associated processes such as:

- Relay-to-EP data channel integrity.
- Per-sample quality as reported by the relay.
- Relay and EP self-diagnostic status.
- Relay settings/firmware verification.
- System state validation via sample magnitude comparison to a minimum threshold.

Such a system can also be used to independently validate protective relay data processing integrity when configured to process measurements from redundant relays connected to a single PT or CT, as specified in NERC PRC-005-6 Table 1-1 [2].

VI. Asset Monitoring Through Use of PRC-002 Data

PRC-002 data can serve multiple purposes that go beyond conventional maintenance and the intent of the regulatory requirements. These data provide immediate insight into asset health that can supplement traditional maintenance programs. The following sections present examples of asset performance diagnostics and prognostics that PRC-002 data can provide. While it is not a comprehensive list, it does highlight a few key areas where PRC-002 data are advantageous for asset monitoring.

A. Circuit Breaker Interrupt Current and Contact Wear

Every time a breaker operates, it endures contact wear proportional to the magnitude of current that it interrupts during an operation. PRC-002 FR current data that a device records during a breaker operation can provide all the necessary information to calculate the interrupt current wear that accumulates on every operation. An automated PSMP can calculate interrupt current wear and track it over time to supplement circuit breaker maintenance.

B. Circuit Breaker Pole Scatter

Pole scatter is the measure of time differences between single-pole breaker operations for transmission lines that use one independent breaker per phase. When the breakers for all three poles operate at the same time, an automated PSMP can measure these time differences using SER data from breaker auxiliary outputs and detect deviations in pole scatter. These deviations provide breaker prognostics to supplement a PSMP.

C. Circuit Breaker Inactivity Time

An automated PSMP can use SER data from breaker operations to track the duration of circuit breaker inactivity. This allows for the detection of circuit breakers that do not operate over a long period of time and assist in prioritizing circuit breaker maintenance.

D. Transformer Through-Fault Current

Reference [6] provides recommended limits for through-fault currents that transformers should endure during their lifetime. An automated PSMP can use FR data to track aggregated through-fault current for transformers, compare it to through-fault protection curves, and warn of impending limit exceedance.

VII. Advanced Monitoring

Some utilities are progressing towards comprehensive monitoring schemes that achieve real-time health diagnostics and prognostics for circuit breakers and other critical assets [7]. Such advanced monitoring schemes include over one hundred characteristics for a single breaker comprising several categories including dielectrics, mechanical integrity, operational wear, and accessories. These systems require aggregated data from numerous sources to detect faulty equipment and, in some cases, project future failures using performance trends. An automated PSMP can facilitate comprehensive monitoring, diagnostics, and prognostics that far exceed those of conventional maintenance programs.

Trip coil monitoring requires direct, post-process analysis of sampled event data [8]. A trip coil's current and bus voltage during a breaker operation provide meaningful performance characteristics including inter-winding shorts, slow-moving actuators, mechanical problems, etc. As Fig. 4 illustrates, key transition points and peak amplitudes expose the trip coil performance and behavior. Mechanical prognosis includes armature alignment and lubrication, which increase armature travel times. Electrical prognosis includes interwinding shorts or insulation failures that demand larger current amplitude to provide adequate electromagnetic force for armature motion. An automated PSMP can record trip coil currents and voltages, process these data through algorithms, and produce trip coil performance reports after every operation. These reports can allow a utility to proactively maintain trip coils before they fail or to provide confidence in future reliability.

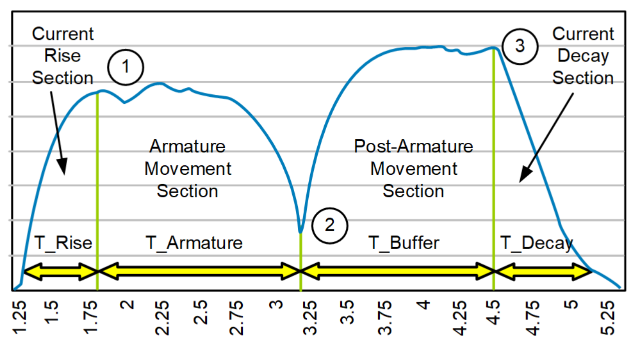

Fig. 4. Typical Trip Coil Current During an Operation

Recent innovations in relay technology have also provided the ability to observe power system behavior using megahertz sampling speeds. Measuring the power system at this rate has led to the discovery of unexpected behaviors that provide more detailed insights into asset performance [9]. For example, examining traveling-wave behavior during breaker operations can reveal breaker restrikes or pole discrepancies. An automated PSMP can potentially use these high-resolution data to cross-examine traveling-wave characteristics from different recording sources to identify failing equipment.

As [10] details, aging capacitively coupled voltage transformers (CCVTs) can cause errors in power system voltage measurements during transient events. Consequently, these errors may lead to undesired relay operations. Failing CCVTs tend to generate erratic voltage signals during power system transients. For example, Fig. 2 from [10] illustrates a corrupted voltage signal from a CCVT that results in errors in the relay fundamental voltage measurement. This corrupt voltage signal leads to bad frequency measurements that impact accuracy further downstream in the relay digital signal processing.

These types of behavior are evident in the raw, point-on-wave event recordings. While traditional relays may not have the capabilities or resources to detect a failing CCVT, an automated PSMP can collect transient data from these relays and process them through custom algorithms to detect corruption in the voltage signals.

VIII. Conclusion

The NERC reliability standards that this paper discusses provide insight into the greater value of data and how data can be used to provide value-added services that increase reliability and decrease operational and maintenance costs. Carefully crafted data collection schemes can aid in compliance with PRC-002 and PRC-005. Several examples demonstrate how to meet PRC-005 requirements by using edge processing and PRC-002 data. Other examples demonstrate the further benefits that automated PSMP systems can extract from PRC-002 and PRC-005 data. These benefits apply not only to electric power utilities, but also to other utilities and industrials that depend on motors, pumps, and generators to maintain reliable production and operation.

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X. Biographies

Darrin Kite earned a B.S. in renewable energy engineering from Oregon Tech and a MicroMasters® in digital product management from Boston University. He works at Schweitzer Engineering Laboratories, Inc. (SEL) as a product development manager in research and development. He spent his first 5 years at SEL as an automation engineer. Darrin is a Certified Information Systems Security Professional and is currently pursuing an M.S. in data science from Georgia Tech University.

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Isaac West received his B.S.E.E. degree in 2011 and M.S.E.E. degree in 2013 from Montana Tech in Butte, Montana. He has been a power engineer at Schweitzer Engineering Laboratories, Inc. since 2013, working in the R&D control and monitoring group.