# How Regulatory Requirements Affect "Protection System" Design and Operation

Abdur Rehman, PE and Paul Luther, Relay Tech
Puget Sound Energy

## I. INTRODUCTION

This paper describes PRC-005 compliance challenges and how protection system design and operations have improved as a result. This paper also reflects on historical designs that are a compliance challenge for engineers and technicians today. And lastly, as a result of compliance and growing departmental challenges, a methodology is presented for creating a systematic and long-term design solutions.

The new PRC-005-6 standard requires documentation and maintenance of all protection systems affecting the reliability of the Bulk Electric System (BES). Circuit breaker trip coils, lock-out relays, CTs tests, reclosing relays, protective relays, and many other devices must be documented and maintained so that "protection systems" are kept in working order. The keyword is *reliability* and PRC-005 helps to prevent *problems* that occur on electrical infrastructure – the problem is often human errors and poor decision making.

A major event occurred on August 2003 in the United States where the ability of grid operators to manage a large scale event was questioned. There were many unknowns and many unanswered questions. Major events in February of 2008, in the southeast USA, and September of 2011, in the southwest USA, are a reminder that power systems are vulnerable to human errors and human decisions.

Human errors are hard to predict however more engineering and planning can reduce the potential for error and avoid unnecessary complex scenarios. Human decisions are much more difficult to manage. Decisions in the electric industry are made every day. Some decisions are simple and require little thought. Others take more time as they are influenced by many people. PRC-005 is intended to take away some of the unknown and help the decision makers make good choices that will increase the reliability of the BES and create a maintenance-positive culture. Equipment maintenance under PRC-005 becomes a challenge when decisions are influenced by budget. Puget Sound Energy (PSE) has transitioned into a maintenance-positive utility. Reliability and sustainability are becoming a priority over cost and budget. Current protection systems and schemes are superior to systems of the past as equipment maintenance is addressed and often provisioned in design.

## HISTORY OF COMPLIANCE & MAINTENANCE AT PSE

Compliance history at PSE and the transition into a maintenance-positive culture has been unique and insightful. A brief overview of the escalating PRC-005 standard may also help in understanding the increasing pressure to properly maintain and operate the BES.

- PRC-005-01: Establish a maintenance program, follow it, and document it
- PRC-005-02: Expanded scope to include batteries, undervoltage, underfrequency, and RAS schemes. Prove monitored relays (microprocessor) are documented in the same manner as non-monitored relays. Definition of Protection Systems requiring testing (lines, buses, transformers, generators, and generator auxiliary equipment).
- PRC-005-03: Expanded scope to include reclosing testing and more documentation
- PRC-005-04: Combined into PRC-005-06
- PRC-005-05: Combined into PRC-005-06
- PRC-005-06: Expanded scope to include sudden pressure relays, voltage sensing and supervisory relays and more documentation

Puget Sound Energy (PSE) has a great history of PRC-005 compliance. The company has been audited three times to date and no fines have been levied against the company for non-compliance of relay or protection scheme maintenance. Like much of the industry, PSE's original maintenance plan was a variation of the honor system. The relays were to be maintained every three years, and documentation was a relay test card attached to each relay. The relay technicians were responsible for scheduling and testing the protection system components. Out of tolerance electromechanical relays were adjusted and returned to service. Microprocessor and solid state relays were element tested. PSE has a strong culture of manually testing relays so there was limited use of automatic testing software. There was no need to document test results. The technicians were expected to return a properly operating relay to service, that fell within the tolerances outlined in the Relay Testing Manual and internal PSE standards.

Trip checks and reclosing checks were done when possible. Line protection relays were maintained and breaker trip checks performed, typically with one terminal open. Transformers, buses, and breaker fail protection were much more difficult to properly test. All instrument transformers were tested at commissioning and hand written documentation was retained. The scheduling authority at PSE, Load Dispatcher (LD), would consider our requests for terminal, transformer, and bus outages. However, like many utilities, it was challenging to get an outage for maintenance purposes. Most trip checks were performed during substation maintenance where the entire substation was offline or during failed equipment replacement where a forced outage was necessary. In general, PSE was trying to do the right thing with equipment maintenance.

After the first audit at PSE in 2010, WECC personnel recommended more maintenance documentation for PRC-005 compliance. The database software used to track relay settings was modified to track relay maintenance as well. All available relays and equipment information was systematically documented in a database to address manufacturer recommendations and warnings. An electronic test form was created to document commissioning tests and all adjustments performed on electromechanical, microprocessor, and solid state relays. This form is electronically stored so past maintenance can be reviewed and troublesome relays can be replaced. Because relay maintenance was performed on a periodic maintenance cycle, the database software was leveraged to track and schedule maintenance. The consistent scheduling and early equipment outage request to the Load Dispatcher led to more cooperation and accommodation for equipment like transformers, and buses.

Two terminal "end to end" testing with time synchronization was becoming the preferred method for testing line protection with communication assisted protection scheme enabled. Due to the nature of dynamic time synchronized testing, logic issues, alarms, reclosing, targeting, setting issues, and communication latency issues were exposed and corrected. Scheme test files and results are kept electronically so future tests can be quickly reviewed and issued. The LD often accommodated line outages because end to end testing required more engineering, planning, and time to correct any issues.

New test equipment was purchased to help improve our testing procedures. A manufacturer recommended test set was purchased to properly test the sudden pressure devices. A previous "go/no-go" test is now replaced with a test that has documentable results that will prove a failed or failing device. Test equipment was purchased to expand CT and PT testing. Previous CT testing required three pieces of equipment to test insulation resistance, saturation, polarity, and voltage development. Relay class and meter class CT's were tested in the same manner. All taps were tested and handwritten documentation was stored in filing cabinets. The new testing method requires one piece of test equipment, tests all available tap arrangements, and all documentation is created automatically and stored electronically. Test templates help drive consistency regardless of the testing technician. CTs and PTs are now tested according to their respective accuracy class and the results are electronically stored. Power System Simulation test sets were upgraded to include multiple communication methods. New higher amperage rated test leads were purchased for each test set. The purchase of IRIG time converters and Universal Time Synchronizers has allowed time synced "end to end" testing to be accomplished in remote locations such as mountainous regions and underground generation facilities.

As a result of PRC-005, there are more tools and support to properly test and maintain protection systems and schemes at Puget Sound Energy. The testing and documentation process continues to be improved and refined. Many new features have been added to the maintenance tracking software. Relay technicians are willing to compromise with difficult scheduling including weekends, holidays, or overnight testing to properly test equipment. However, new challenges emerge as the scope of PRC-005 expands.

## II. "PROTECTION SYSTEM" DESIGN, OPERATION, & HUMAN CHALLENGES

Although new protection systems and schemes are provisioned for testing and maintenance in light of PRC-005, past designs were not. Many older substations, control panels, and even protection schemes were initially designed with little consideration for testing and maintenance. Sometimes designers were restrained by budget. Other times innovative ideas and solutions were created which resulted in more complexity. Sometimes it was an industry problem while other times, it was purely "that's how we've always done it." Some of these challenges are outlined below.

### LOW COST BIDDER

In some utilities, there is a policy of selecting the lowest cost bidder for heavy equipment acquisition like circuit breakers, transformers, Gas Insulated Switchgear (GIS), and Metal-Clad switchgear. This is a common practice to keep prices low and avoid single sourcing a manufacturer. Consequently, this leads to many other problems over the life of the equipment especially during maintenance testing per PRC-005. Different manufacturers and vintages of circuit breakers, protective relays, transformers, GIS, and metal-clad switchgear are installed throughout the system. Spare parts must be maintained per manufacturer and vintage. Maintenance crews must learn to properly maintain many different mechanism designs. Each different component requires unique prints, wiring connections, alarm activation, operational procedures, and test connections. This adds time to the process and sometimes leads to testing mistakes due to unfamiliarity and lack of training. This is an industry wide problem.

### OVER COMPLICATION

Microprocessor relays have allowed incredible flexibility for protection engineers. Nearly all modern and some legacy relays offer custom logic and unique options for protection. These relays provide multiple setting groups, multiple timers, inputs, outputs, event recording, fault location, and custom logic. Improper design or budget limitations could now be addressed within the relay directly – which was not available in the past. Some examples include a single breaker protecting two lines or using reverse zone distance elements to protect a non-conventional bus. This could also add unnecessary complexity during maintenance testing resulting in errors and mistakes.

PSE has substations designed with a single transmission breaker protecting a line with distance protection looking in both directions with a single pair of relays. Relay 1: Zone 1 and 2 looks forward; Zone 3 and 4 looks reverse. Relay 2 has a similar setup. This unique and complex solution was developed due to improper design and/or budget limitations. Additionally, some locations were not provisioned for a future second breaker which adds to the difficulty of upgrading the protection scheme to current standards.

PSE, like most utilities, has ultimate build designs for most substations and provisions are put in place to allow for future expansion. However, substantial deviation from the ultimate design can lead to confusing and complex protection schemes. Operating a bus arrangement differently from its intended design, such as a breaker and a half arrangement operating as a ring bus, makes everything excessively complicated. Control panels constructed to the ultimate design but operated and tested to the temporary bus configuration can lead to mistakes when attempting to meet PRC-005 compliance. More time is required for technicians to familiarize themselves with temporary configurations before any testing is performed. Temporary configurations to accommodate cost constraints are a problem. Long term operations, many times over ten to twenty years, in a temporary configuration lead to unnecessary complexity. Proper initial construction would avoid many future costs. Technology and protection philosophy changes may render the temporary operation configuration too difficult to convert to the ultimate design without significant expense and retrofitting, especially twenty years after initial construction. A properly designed initial build, with a standard operating scheme, such as operating a breaker and a half as a breaker and a half, is closer to achieving the ultimate build than a temporary configuration that may need to be scrapped to obtain the ultimate build design. Achieving the ultimate design build is progressively difficult without continuous construction, testing, and commissioning towards the ultimate design.

**NON-STANDARDIZATION**

Many companies struggle with standardization so PSE is not alone. Field personnel often criticize non-standardization of substation equipment. With increasing equipment complexity, standardization becomes more challenging. Equipment features, such as communication ports and protocols, alarm outputs, and the increasing presence of microprocessor based relays and controllers require the standards engineer to increase their knowledge of the products. Increased interaction with operational groups that are the end users of all this advancing technology is also very valuable in obtaining the standardization of a new product. Protection and Control engineers, Relay Technicians, Substation operations, and SCADA personnel all have a stake when a new standard is being created. Simple oversite and dismissing even the smallest details can disrupt an otherwise well thought out improvement. More examples of non-standardization without proper vetting will be described later in this paper.

Similar to many utilities, PSE has evolved in small increments. Technology is often driven by a single department without cross-departmental support. For example, the integration of advanced communication protocols in substations was not fully standardized at PSE. There are a great many unique DNP lists in the system which causes confusion when changes are to be made, or when new equipment is added within existing substation. Often times, the communication programming must be rewritten and retested for an entire substation. This could have been resolved with standardization.

Unspecified and unregulated construction practices of the past allowed non-standard test switches for periodic relay testing. Non-standard test switches were purchased with the introduction of microprocessor relays. The test switches have no known test block and have awkward test equipment connections. With PRC-005 and a specific testing schedule, relays with these test switches are visited more often. Three phase test connections associated with dynamic testing are cumbersome at best, with direct connections to the relay more reliable than through the test switch. Time is unnecessarily wasted with this switch and it has been rendered obsolete by the manufacturer. Major manufacturer electromechanical relays come with either a built in test switch or a standard test block for safely connecting to the relay. This tried and true technology was ignored. The decision to purchase and install the non-standard test switch was on the basis of cost and created an unregulated maintenance practice.

Designs of the past include lockout relays with no isolation which caused difficulty in maintenance trip checks. When a bus outage is approved, it is preferred to operate the lockout relay as designed. This ensures DC control system integrity when tripping multiple breakers at once. Receiving an outage on an entire bus may not always be possible. To complete the PRC-005 maintenance however, blocking material is inserted in series with the contacts of the older style of lockout relays. Newer lockout relay styles do not offer the same option as the contacts are encased within the housing of the relay. Lifting wires for breakers that must remain in service is the only option when testing these bus lockout relays. The omission of isolation points for lockout relay trips clearly obstructs PRC-005 compliance.

Another challenge for PSE is the lack of communication equipment prints and SCADA point name standardization within substations. Many PSE substations have no communication prints that explain how each piece of communication equipment is connected and/or located. The increasing presence of communication equipment in the substation control house has forced documentation onto substation prints. Troubleshooting becomes difficult without communication prints. Safe equipment isolation in the event of equipment failure also presents a challenge. Non-standard SCADA point name conventions with varied nomenclature is also challenging. The same alarm at two different substations could have a different name in SCADA and EMS; the inconsistency makes alarm interpretation difficult for system operations. These challenges were addressed by the Operation Technology Working Group and will be discussed later in the paper.

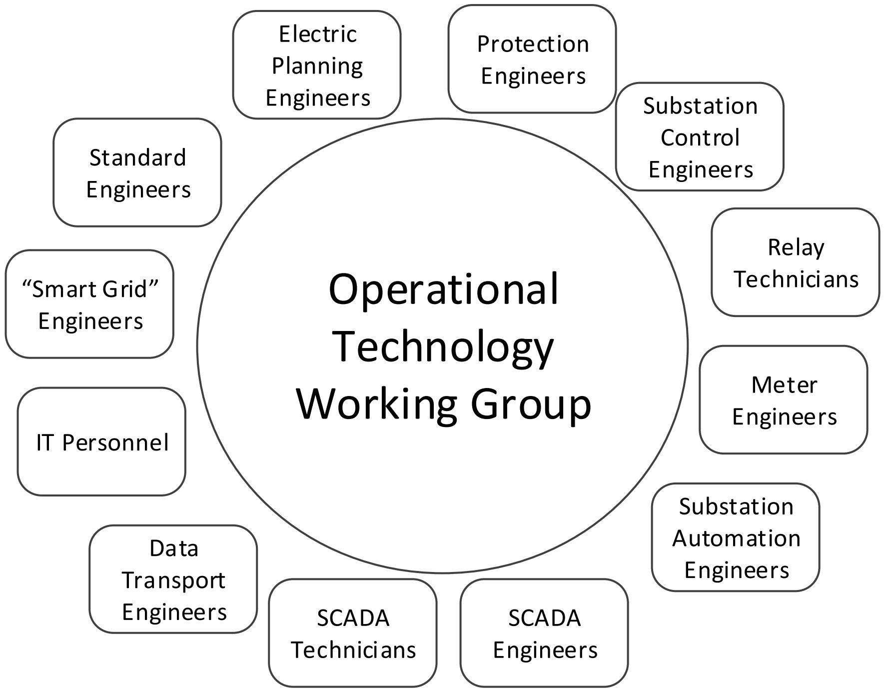
### OLD HABITS & NEW SUPPORT

Breaking old habits is challenging for relay technicians. The group operated with a philosophy of only testing an entire relay scheme during commissioning. Testing protection schemes included tripping breakers, proving communication assisted trip logic, testing reclosing, tripping lockout relays, verifying DC systems, and testing sudden pressure relays. Now, these tasks are required at all maintenance intervals. Relay technicians are apprehensive to test in a manner that may produce unwanted and unpredicted results due to complex and challenging designs. Errant trips are not taken lightly. Instead of satisfying PRC-005 to the letter, PSE has surpassed the basic requirements and tested schemes as a complete system. Training, engineering support, and experience have made this possible.

## III. OPERATIONAL TECHNOLOGY WORKING GROUP & LONG TERM SOLUTIONS

Engineers are natural problem solvers which is a double edge sword in the utility industry. Short-term but unique and innovative solutions are implemented forgoing the “right thing to do” and industry best practices and proven solutions. Sometimes this occurs because of a rogue engineer striving for the cheapest solution. Sometimes this occurs due to no support from other departments. Sometimes the right solutions are not favorable due to time and budget constraints. Sometimes cost-saving solutions are rewarded with promotion and praise. When engineering designs fail and misoperations occur on the BES, the loss of utility revenue is tremendous and corrective action plan becomes very expensive and mandatory due to NERC PRC standards. These challenges must be addressed systematically.

Puget Sound Energy is actively pursuing a methodical approach for long-term solutions to “Protection Systems” and “systems” in general. This approach is driven by the need to comply with growing regulatory requirements, prevent short-term fixes and increased trending of cross functional solutions impacting multiple departments, and general industry trends for IT infrastructure in substations. Part of the solution is to formally engage all representing departments through a peer-to-peer committee. This prevents communication gaps, establishes a formal “buy off” process with all representing parties, and allows everyone to think long-term before system implementation or modification.




The Operational Technology Working Group (OT WG) includes Engineering Design and Planning, Informational Technology, and Operational stakeholders. They meet monthly to fulfill their mission "To improve system design, installation, commissioning, operation, and maintenance of the PSE electric grid and communications network by developing cross functional solution and knowledge transfer". All proposed designs and equipment must be reviewed and accepted by the OT WG before implementation. This process requires more scheduling, planning, engineering, design, and analysis.

For example, suppose System Protection Engineering wants to implement identical relays for 115kV transmission line protection to streamline settings and allow full redundancy. So Relay 1 (primary) and Relay 2 (secondary/backup) were the same brand and type of relay. They work closely with Substation Control Engineering and develop the scheme and prints for this new design. Once they have a working system, both groups present this scheme to the OT WG. At the meeting, the Relay Technicians get an opportunity to hear about this proposal. They suggest making the Breaker Failure feature very clear since the proposed changes affect their work practice. They also suggest an offline meeting for additional questions and clarifications. Next, SCADA engineers ask how the relays will communicate with the RTU. They would like to see relays connected via Ethernet instead of serial. The SCADA technicians chime in and ask to get a standard points list implemented in the RDB making their job easier in the field. Meter engineers are concerned about NERC TOP-006 testing so they ask about the CT ratios and any limitations in the relay. Standards Engineers ask if the proposed relays are coded in the Material Catalog and offer assistance if needed. Planning Engineers want to know when the new design will be ready for implementation so they can avoid an aggressive build schedule. Maintenance personnel see this as an opportunity to track breaker information which can be used for a future preventative maintenance plan. An offline meeting is proposed to discuss how the new platform can support their maintenance activities.

Relays are one example of a cross-functional system that affects many departments. The OT WG allows each department to address concerns about their portion of the system. The environment has been established for that particular purpose. It's a neutral playing ground where giving and receiving feedback is celebrated because it improves the long-term reliability of the system. Regularly scheduled OT WG meetings allow all parties to secure time on their calendar early in the year. Typical design and operation meetings have many shortcomings. It is challenging to secure key representatives in a meeting due to scheduling conflicts. With organizational changes, it becomes difficult to know who the right representatives are. Politics and infighting during meetings can hinder the long-term viability of a solution. In addition to improving designs, the OT WG is also a place to share technical knowledge.

The need for Communication Assisted Tripping for transmission line protection is growing at PSE. There is a clear need for some lines due to system configuration and constraints. Other lines with marginal time-overcurrent coordination clearing would certainly benefit. Although there is Operations Network connectivity at many substations, dedicated or leased fiber optic cables are expensive to install for Communication Assisted Tripping between two substations. The IT group proposed an IT solution with high reliability (99%+ uptime) and adequate speed and latency for Communication Assisted Tripping. Communication bits would use the Operations Network as a transport medium instead of dedicated fiber optics. After receiving favorable feedback, the IT representative started working on a solution. After several months, they prepared a slide deck presenting the technology and the basic building blocks of the concept.

It was very interesting to hear the concept presented by IT in the early stages of development. They were open for comments, questions, and feedback and additional cross training between specific groups. The PSE IT department is quite segregated and isolated from the rest of the company. Because traditional utility engineers do not understand the world of IT, it often becomes a point of contention, confusion, and frustration. This example describes the mission of the OT WG – which is to share and transfer knowledge between departments.

Another example that describes how OT WG improves cross-functional system design is related to control prints and communication systems. The need for substation control engineers to produce high quality control prints is driven by safety, system design, and reliability. Substation control prints are very detailed and a small wiring mistake may cause an entire system to malfunction. The utility industry as a whole produces and maintains high quality substation control prints. The same isn't true for communication/SCADA systems. If the communication architecture is established, connecting substation devices is simple and straightforward. They are easier to troubleshoot and make it work in the field during testing and commissioning. Once the communication systems are working and tested, little maintenance is required.

In many utilities, there are no prints for communication systems. SCADA Engineers and technicians can't say with confidence that device A on Port X is connected to device B on Port Y using Z cable. This was the challenge at PSE and the OT WG helped mitigate this challenge. The Substation Control Engineers urged the SCADA team to develop prints to show how substation communication devices were connected. After discussing its value, the SCADA team agreed and started implementing the practice established by the OT WG.

Although the OT WG has some great benefits, there are some challenges as well. Sometimes there is a rapid reaction to new technology or system. The OT WG can get side tracked and go after the latest and greatest technology despite it being untested. When there are no new topics presented, it becomes difficult to engage all stakeholders. It becomes more difficult once the needs of a particular stakeholder are fulfilled. Without a strong consistent leader running the meeting, valuable time is wasted between transitions. Sometimes a single group or person can take over the OT WG and use it as a sounding board for their own agenda. Although there are challenges, the benefits are quite extensive.

The OT WG enhances the reliability of systems cross-departmental review and suggestions. NERC Standards are discussed and provisions are made when implementing new designs. It allows systems to be standardized for efficiency, consistency, and longevity. The OT WG calls for improved and flexible designs and it breaks departmental silos and isolation.

## IV. CONCLUSION

NERC PRC-005 helps to prevent problems that occur on electrical infrastructure – the problems are often related to human error and resulted from poor decision making. A brief history of compliance at Puget Sound Energy was provided to establish context for maintenance challenges. Many examples of protection system design, operations, and human related problems were presented such as low cost bidder, over complication, non-standardization, old habits. Furthermore, the Operational Technology Working Group was discussed as a vehicle to create long-term and systematic solutions that bring all the stakeholders around the table.


## ABOUT THE AUTHORS

Abdur Rehman joined Puget Sound Energy in 2013 as an Engineer-In-Training after earning a BSEE from Washington State University in Pullman, WA. Upon rotating in various groups within PSE, he accepted a position in System Protection where he worked as the primary protection engineer in Kitsap County. Abdur then transitioned into a dual field and NERC Compliance role within the same group. He currently supports the Relay Operations group with testing and commissioning protection systems and relay schemes. He also supports regulatory compliance for engineering and relay operations including the PRC and CIP standards. Abdur is a registered PE the state of Washington and currently pursuing his MSEE at WSU. Prior to joining PSE, Abdur interned at Tacoma Power, Schweitzer Engineering Labs in Pullman, and Maple Systems in Everett.

Paul Luther worked his way from Helper to Apprentice Wireman to Wireman and is now a Relay Technician at PSE. Paul has had extensive experience constructing, testing, commissioning, and trouble-shooting utility electrical equipment throughout his career at PSE (22 years) and SDG&E (5 years). He actively participates in training junior technicians at PSE and is involved in the Hands on Relay School in Pullman, WA as a presenter, facilitator and instructor.