Practical Considerations and Experiences in Developing New Standard Production Packages for Protective Relay Schemes

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Abstract—Duke Energy Carolinas Transmission Protection and Control Engineering has refocused our approach to developing new standard production packages. Technology, operational restraints, regulatory requirements, maintenance, testing procedures and workforce capability have necessitated the development of new production standard packages for protective relay schemes. Years of utility experience in design, operation and maintenance of protective relaying schemes has provided insight and direction in developing new production standards for both greenfield and brownfield applications. Challenges and shortcomings of inadequate or under-developed production standards have provided understanding and guidance into the development of flexible and upgradeable production standards. In addition to engineering and design perspectives, field testing and commissioning personnel, system operations, transmission planning and Duke’s enterprise standards organization were consulted in the development process. This paper examines the need for utilities to develop production standard packages for protective relay schemes as well as what prompts the development of new production standards. A discussion of the considerations in developing new production standard packages is included to provide a basis for decisions made in the development process. Examples of these decisions include reducing the complexity and functionality within each device, implementing common look and feel across schemes, testing and certification of logic, along with many others. Finally, a discussion of the experiences during standards development is provided to give practical insight into the process of developing and implementing a new production standard. 

Keywords—standards, production standards, protection, transmission system, settings, design, templates

I. INTRODUCTION

In recent years, the Duke Energy Carolinas Transmission P&C group has refocused its approach to developing new standard production packages. This paper starts with a short discussion on what we believe should be included in a standard production package, what prompts the need for a new standard, and what benefits are obtained from having a well-engineered and well-developed standard production package.

This is followed by a section titled Areas of Consideration, where a discussion of the considerations that should be taken into account when developing a new standard production package is provided. Following this, a discussion of the experiences during standards development is provided, giving practical insight into the process of developing and implementing a new production standard. This section is titled Application Outcomes of the Decision Making Process and provides insight into the many lessons learned during this journey.

II. WHAT SHOULD BE INCLUDED IN A PRODUCTION STANDARD

The phrase “production standard” means different things to different utilities or design firms. Our practice of what should be included in a “standard design package” may be quite different than what others believe should be included in one. Years of utility experience in design, operation and maintenance of microprocessor based protective relaying schemes has provided insight and direction in developing new production standards. Our definition of a “production standard” includes standard utilization of inputs and outputs on specific relay models, standard and repeatable design drawings, standardized relay logic, and repeatable setting templates. In order to maximize the benefits of a production standard, standardized setting templates must be included as a cornerstone of any new standard. Relay logic that is modified, altered, or customized per location, corrupts the true meaning of “standard”. The shortcomings of inadequate or under-developed production standards have provided understanding and guidance into the development of engineered flexibility and upgradeable production standards. Further discussion on these issues is provided in a later section of this document.

III. WHAT PROMPTS THE NEED TO DEVELOP NEW PRODUCTION STANDARD

There are a number of drivers that can generate a need to develop a new production standard. One of the main drivers that necessitated the development and implementation of our current production standards was older electromechanical and solid state relays reaching their end of useful life in large volume. With an urgent need to find a repeatable solution to replace a large volume of relays testing out of tolerance, we engineered a “replacement package” designed to facilitate the replacement of not only the bad relay, but the line protection package as a whole. While the electromechanical relays were the first to present this
challenge to us, the early generations of microprocessor relays are now posing the same problem. The initial rush to install some of the first generations of microprocessor relays over 20 years ago caused some issues. There was not enough time to fully develop standard design packages, and as a result highly customized “one-off” designs were created. These issues have provided current lessons useful in developing our new standard design packages (this will be discussed in later sections of this paper).

Another driver that can trigger the need to develop a new production standard is when a manufacturer decides to stop offering a current model that is being utilized in an existing standard. Should a manufacturer decide to stop producing a specific model, a new model (or models) will need to be selected to develop a replacement standard production package. In some cases, the manufacturer’s newest offerings may provide new technologies or features (synchrophasor measurements, fault location, communication, etc.) that will encourage the movement to a newer standard production package. However, simply moving to the latest and greatest technologies does not come at zero cost; in addition to maintaining all of your existing production standards from a settings and setting template perspective, you now have a new design that needs attention and maintenance.

Other drivers are “outside” influences that can trigger the need for new production standards (“outside” referring to outside of the daily production P&C group). For many large utility companies, corporate internal policies, negotiations and equipment standards groups can have an influence on vendor and relay model selection. While these decisions are made within a corporation (and with the input from P&C groups), they can trigger the need for a new production standard. Another “outside” influence is compliance and possible future prescriptive redundancy requirements by regulating entities. While historically this has not been a key influence in previous production standards, future compliance requirements could drive changes in current company specific practices and production designs.

IV. WHAT ARE THE BENEFITS OF PRODUCTION STANDARD PACKAGES

A well-engineered (and thoroughly developed) standard production package (relay, design and setting template) that can be used in many repeated applications, will reap tremendous benefits to all parties impacted. The repeatable solutions offered by standard production package offer benefits to the engineering organization, field performers, operating personnel, SCADA Engineers and Control Centers. The benefits for each of these organizations and groups are shown below:

**Engineering Organization Benefits**
- Quicker Engineering Time
- Reduced Training Time for New Engineers
- Standard Design Drawings/Packages that can be implemented
- Standard Setting Templates

- No or very minimal logic changes (will significantly reduce the number of settings errors). Eliminates (or reduces) the need to test many versions of logic in the lab

**Field Performers**
- Faster Installation, Testing and Commissioning
- Standard Testing routines can be used for standard packages that use standard logic
- Pre-developed testing routines insure more thorough testing of the relay
- Less experienced field performers can be used for the field commissioning
- Minimizes the “red marking” of design drawings issued to the field organization

**Operational Benefits**
- All installation have panels with the same look and feel.
- Minimizes amount of training required for those who operate the system.

**Control Center and other SCADA Benefits**
- Standard Alarm Lists for each installation
- Standardized I/O summaries that do not need developed for each installation and use of customized logic.

V. AREAS OF CONSIDERATION

**A. Applicability Considerations**

When developing standard protection and control packages, it is important to consider the applicability of the package, or how the package is applied across the system. The applicability can be thought of in terms of how often or how widely the package is used. For instance, it may not be desirable to invest the time, effort, and money into the development of a standard package for a one of a kind application. Instead, development of standards should be focused more on schemes that are widely used throughout the system. In these instances, repeatability is key. Applicability can also refer to how, flexible the design needs to be. For example, the variability in bus arrangement may need to be considered. Additionally, in the planning stages of the project, effort must be taken to apply the developed standard wherever possible. Unnecessary deviation from the use of standard packages places both engineering and field personnel in a difficult position. Instead of a standard design, they must interface with varying schemes. This increases the likelihood of error in application, design and operation.

**B. System Design Considerations**

Protective schemes do not exist in a vacuum. The physical design of the electrical system around the protective scheme will have a large impact on any new standard development. Bus layout and system stability have the greatest effect on protection systems. A high variability of bus layouts (single bus, double bus, breaker and a half, ring bus) on the system can greatly increase the difficulty of designing a standard protection system. Each of the different bus layouts has different requirements for reclosing control and breaker
failure that must be taken into account. In contrast, if a system is almost entirely one bus arrangement, it is far easier to incorporate into a production standard.

System stability concerns also affect the development of new standards. Critical clearing times can become very challenging depending on the protected equipment and the inherent instability of the grid at that asset’s location. Questions regarding which protective elements should be used and how to design the breaker failure scheme become very important. Examples include, the use of a physical lock out versus a software lock out, or an external breaker failure relay versus an internal timer, and many more options affect the overall time to trip that counts against a critical clearing time.

The system requirements can also change over time. Critical clearing times can become slower or faster, reliability requirements can become more stringent, and breaker arrangement can be changed. Design standards should be flexible enough to handle system changes with as little redesign as possible.

C. Operating Considerations

Great consideration should be given to the ease and convenience of operation of any standardized protection and control scheme. The end users of any protection and control design are not the members of the protection engineering department, but rather the control centers and field operators who must operate the system on a daily basis. A lack of a design standard can cause unnecessary operational confusion between stations, or even between assets in the same station. Also, a poorly thought out design standard can significantly limit the flexibility of the operators and create human performance traps. This is not to say that the operators of the system should be able to dictate exactly what they want in every protection scheme. What they think they want may, without their knowledge, be detrimental to the health of the system. It is up to the protection engineer to balance the needs and requirements of the protection system with the desires of the operators when developing a standard. Input from operating is required, but ultimately the protection of the public and the system is primary.

Consistency alone can greatly reduce operating complexity. For example, similarities between panel layouts for auto-transformer and transmission line protection can be incorporated into the design standard. Choosing a physical design that operators are familiar with, and then projecting that high level layout across all protection schemes can lead to an intuitive sense of where each component of the protection scheme is located.

In modern microprocessor relays, the physical layout is not the only place that inconsistency of design can cause issues. A standardized software layout can also aid operation. Using the same logic elements for the same purpose makes developing the alarming and control functions much easier. For example, if a software latch (Latch#1) is used for a breaker failure trip in a line protection relay, and Latch#1 is used as breaker failure trip for every protection scheme developed after that, the alarm point Latch#1 becomes synonymous with breaker failure. Developing alarm I/O maps becomes much simpler scheme to scheme when the majority of the alarms and statuses are pre-defined. Developing remote controls for a modern relay become easier to design when the majority of the internal control points are pre-defined. Standardizing the high level software layout can reduce the learning curve of new operators by making what they see consistent from scheme to scheme.

The ability to take equipment out of service is extremely important. The best way to perform this function will vary from utility to utility. For instance it should be considered whether to use pushbuttons on the front of the microprocessor relays or a separate physical cut-out switch or other logic internal to the relay. Each option has its own unique benefits and drawbacks. The pushbuttons are easy to use, and most microprocessor relays have programmable LEDs that can be programmed to specific logic points to light up when elements are blocked. However, it could be said that for some protective elements the pushbuttons are too accessible to use. You may want the operator to have to spend time operating a cut-out. In those instances the internal software blocks that must be accessed through a longer process may be appropriate. However, neither the software blocks nor the pushbuttons allow for any real physical disconnect available with external cut out switches. In terms of manual tripping and closing of breakers more questions arise.

D. Maintenance Considerations

It is important to remember that any standard design is not created or implemented in a vacuum. Designs must be viewed, not only from an initial application and installation point of view, but also from a maintainability viewpoint. Designs, once installed, will be in service for the life of the equipment, and must be maintained in the interim. The maintainability of the design not only includes replacing failed components, but also, and possibly more importantly, preventative maintenance and testing. If no consideration is paid to maintainability, even a design that is easily operable, widely applicable, and repeatable may be an ineffective design. Among the considerations that should be given to the maintainability of a standardized protection and control scheme are the location and arrangement of the equipment in the scheme, the isolation of the scheme, and tests that must be performed on the scheme as a part of the preventative maintenance program.

The location and arrangement of the equipment in the protection scheme is an important consideration when it comes to maintenance. If the different components of the scheme are not arranged in an effective manner then the scheme will not be able to be maintained. For instance, a scheme that is arranged with the most commonly accessed components placed at either the very top or the very bottom of a panel would make it difficult for maintenance personnel to perform the necessary maintenance activities. Additionally, if the components are arranged in such a way that the components are placed too close together, the space constraints can make the scheme difficult to maintain. Also, even though it may not be applicable to the individual scheme, the placement of the scheme within the control house should also be considered.
when it comes to maintenance. Panels should be arranged in such a way that makes the wiring less complicated and easier to troubleshoot. Another consideration that applies to the arrangement of the scheme is the number of panels that should be included in the scheme. For instance, a distribution feeder circuit protection scheme may be arranged such that multiple circuit exit protection schemes are on one panel, while a 230kV line protection scheme may utilize two separate panels line. The decisions around the panel arrangement are maintenance considerations, because the density of the equipment on the panel can affect how easily it can be maintained.

Another important maintenance consideration that should be accounted for in the development of a standardized protection and control scheme is isolation. When designing scheme isolation, one must consider not only the ability to isolate the protection scheme as a whole, but also the ability to isolate individual components of the scheme. This is necessary not only for the installation and commissioning of the scheme, but also for the preventative maintenance and periodic testing of the scheme once it has been placed in service. The ability to isolate the scheme as a whole is important, because it is necessary to work on the scheme and/or protected equipment while leaving the rest of the station in service. Difficulty incorporating this type of isolation can occur when more than one line protection scheme is on a single panel. It is easier to isolate the scheme when there is only one line protection package per panel. Isolating parts of the protection and control scheme may refer to either a primary or secondary relay, or to individual outputs. For critical protection schemes it may be desirable to isolate either the primary or secondary schemes for maintenance while leaving the other in service. This may allow the protected equipment to remain in service while part of the protection scheme is being maintained. An evaluation of the necessity of such isolation should be made in the design process. Some applications may require such isolation, but not all schemes will. The ability to isolate inputs and outputs of the system is also an important consideration. This affects the placement and number of test switches, and can have an impact on the ability to test and commission the scheme. For instance, only tripping, voltage and current inputs and outputs had previously been isolated through test blocks, but you may wish to take all inputs and outputs through the test switches.

The ability to perform the required testing of the scheme is an important consideration related to maintenance of a standard protection and control package. It is important to remember, with all of the regulations and requirements to test and prove the operation of schemes, that accommodating testing is extremely important. It does not matter how well developed or enhanced a scheme may be, if it cannot be tested it should not be implemented. Therefore, the types of tests that have to be applied to the protection scheme need to be known and accommodated in the design of the new schemes. This includes not only the ability to prove the performance of individual components such as relays, but also the overall performance of the scheme such as trip path testing. Each of these maintenance considerations is important to be incorporated in the development of the standard protection and control schemes.

E. Compliance Considerations

In an environment of increasing regulatory monitoring, any new protective system design must consider compliance with regulatory bodies. Regulatory requirements govern and impact almost every aspect of protective systems. The two main areas that compliance requirements should be taken into account for new design standards are design and long term maintenance. Initially, PRC-001 (System Protection Coordination) has a major impact on a new standards development. Within PRC-001, requirements R1, R2, and R6 are of particular importance. R1 states that every “Transmission Operator, Balancing Authority, and Generator Operator shall be familiar with the Purpose and limitations of Protection Systems applied in its area.” R2 touches on who to notify, and when, for Protection System equipment failure. R6 states that any Special Protection System must be monitored and any change in status must be communicated. Any new protection system standard must be able to facilitate ease of compliance with all three of these requirements. Any new standard design should be easy to understand and have enough reliability built in that the protection system can withstand some component failures without reducing system reliability. Any new design that involves a Special Protection System (SPS) should make the monitoring of that unique system easy. In regard to installing new SPS schemes, PRC-012 through PRC-017 are of particular importance in the design stage. These requirements regulate the entire approval process, maintenance, and redundancy of SPS. How SPS should be implemented into protective systems is a difficult question that should not be passed over quickly.

The compliance needs associated with a standard design do not cease after installation. For long term maintenance, serious design questions need to be asked. PRC-005 sets the requirements for maintenance and testing plans of protection systems. A new standard design should take into consideration ease of testing and maintenance so that the field organization has as few obstacles in its way to meet compliance as possible. When doing this, a discussion is necessary with field operations to determine exactly how they test equipment, how they take relays out of service, and what they would prefer when performing their tests. In our own experience these discussions have frequently produced results that were different than what we would have initially designed. In our own attempt to make things easier to test, we would have actually made it more difficult had we not sought advice from the field.

F. Human Performance Considerations

An important thing to remember when developing standard protection and control packages is that, even though the scheme is made of different pieces of hardware and software, it is designed, installed, operated and maintained by humans. This is important to remember because humans will make mistakes. Any standard design should be designed in such a way to reduce the probability of human errors. The
consideration of the different aspects of the design and how they can be implemented to reduce the number of human errors is called human performance.

When considering human performance and how it impacts the design of a standard protection and control package, one must first understand that tasks, including those that involve the design and implementation of the standard package, fall into three different categories. The three categories of human performance are knowledge based, rule based and skill based tasks. Knowledge based tasks require a high level of knowledge to be performed and are the most likely to experience human errors. An example of a knowledge based task is taking a calculus test; it requires a specific set of knowledge and it is fairly easy to make an error. Rule based tasks are less likely to have errors and are the type of tasks that can be implemented with the aid of a checklist or procedure. An example of a rule based task is voting; a task that is not done regularly enough to be second nature, but with reading the directions and walking through it step by step it is easy to accomplish with minimal error (though it is not immune to error). The final type of task is the skill based task, which can be thought of as habits or tasks that are easily repeatable without much thought. These are the least likely to have errors. An example of a skill based task is washing your hands; a task that can be done repeatedly without error and with minimal thought and preparation. Given the different types of tasks, any design change during the standard package development process that would enable a knowledge based task to become a rule based task, or a rule based task to become a skill based task, the better insulated the design will be from human performance errors.

Other considerations from a human performance point of view include creating a common look and feel across different standards. By creating the common look and feel, it becomes more familiar to everyone and the familiarity reduces the likelihood of errors. Another consideration is the use of consistent and understandable terms for components of the standard package.

**G. Historical Considerations**

It is said of the past, that if we don’t learn from it we are bound to repeat it. This philosophy should be followed during the development of new standard protection and control packages. It is important to consider the protection schemes of the past in the development of new schemes, because we can improve on deficiencies and carry forward successes. While the designs of the past work and have been in service for years during the development of new standards, it is important to consider the strengths and weaknesses of past designs. By examining the past designs it is possible, with the benefit of hindsight, to apply well developed and thought out concepts to the standard. Sometimes, this means taking a look at what was done previously and deciding that it was not good and making sure that it is not repeated in the future. Conversely, it can mean finding something that worked very well and carrying it forward into the new design.

Another impact of historical considerations is that the new standard protection and control package must often times interface with existing schemes and designs. While it is easy to implement and design a standard that can be applied in a green-field application, developing a standard that can be implemented in a brown-field environment is also key. While it might be decided that it is beneficial to have different green-field and brown-field applications it may also be desired to develop a standard that is applicable to both. Either way, this is a consideration that must be taken into account in the development of a standard protection and control package.

**H. Technology Considerations**

In a world where technology is evolving at such a rapid pace it is important to consider the technological implications to developing a standard protection and control package. It is important to consider the capabilities of the different components in the standard package. For instance, if the standard is for a system that includes two breakers and it is desired to have the currents for each breaker brought individually into the relay, the relay must be capable of having separate current inputs. It is also important to make sure that the components used are not obsolete and are still available from the manufacturer. Also, consideration should be given to how far the standard should push the technological envelope. While keeping standards technologically up to date is important, it may not be desirable to be on the bleeding edge of technology with a standard package. Typically, standards are designed to implement a solution that is known and understood to minimize issues and errors.

**VI. Application Outcomes of the Decision Making Process**

**A. Reducing Complexity Within a Single Relay and Layered Schemes**

Duke Carolinas West decided upon two high level designs; one for 44kV and 100kV assets, and one for 230kV and 525kV assets. These designs were picked to allow a layering of protective applications, and to reduce the overall complexity of the design. At the 100/44 kV levels, protection and control was split into two relays. Both relays provide the same primary protective elements, and both relays provide back-up breaker failure protection. The only difference between the primary and secondary relays is that the primary relay alone provides reclosing control. Breaker failure and reclosing control was kept internal to the protective relays since the vast majority of 44kV and 100kV stations in Duke Carolinas West have the same double bus design. Since there is not a stand-alone breaker failure relay, both the primary and secondary relays have breaker failure activated to allow one of the relays to fail without losing back up protection. Every breaker has its own stand-alone manual trip and close controller. Cut-outs for most protective applications are handled through pushbuttons on the front of the relay; however breaker failure cutouts and a remote control cutout are handled through internal software blocks. External lockout relays are used for breaker failure tripping, and external tripping relays are used for bus differential tripping.
At the 230/525kV levels protection was split between two relays, while breaker failure and control was placed into its own relay. The protective relays can be mixed and matched with various primary protective elements (POTT, 87L, DCB). The breaker failure and control relay performs the breaker failure function or reclosing. This design was selected due to the high variability in bus design at 230kV and 525kV on the Duke Carolinas West system at these voltage levels. Splitting breaker failure and control into a separate relay allowed for a standardized protection settings template for any POTT, DCB, or 87L application regardless of breaker layout. This also allows the protective relays to be taken out of service without removing the breaker failure protection. Every breaker has its own stand-alone manual trip and close controller. Cut-outs for most protective applications are handled through pushbuttons on the front of the relay; however breaker failure cutouts and a remote control cutout are handled through internal software blocks. External lockout relays are used for breaker failure tripping, and external tripping relays are used for bus differential tripping.

Any SPS applications needed on an asset are to be treated as a totally separate relaying application. The relays that perform the SPS application will be different from the relays that perform the normal protection applications. This allows the normal protection applications to maintain a standardized settings file and design. The SPS, which will be highly variable and dependent upon each application and site, will be isolated from protective relays when they need to be blocked.

These design decisions reduce complexity even though more wiring may be required. Complexity, however, should be viewed not just from a wiring standpoint but also from a logic and settings standpoint. The design balances the tradeoffs between wiring and logic to achieve a less complex system overall that allows for easier design, application, testing, and maintenance. Simplicity is not always a lack of wiring, but also takes into account the entire process in creating a protective system. Keeping breaker failure lockouts external adds a whole relay and many more wires and contacts. However, the alternatives significantly increased the complexity of testing, and would have dramatically increased the complexity of the breaker failure and control settings templates for 230/525kV applications. Keeping any SPS separate allows the protective relays to have no uniqueness about their protective settings and logic, and keeps a SPS from being affected by normal maintenance on the protection. Many of the decisions in the standards’ development simplified through separation. All relays involved are multiple function, but only the functions that were determined could be applied to those relays and maintain an actual standard were added. Too much functionality per relay results in customized designs both physically and in settings. Customization hampers the efforts of engineers and technicians to quickly and correctly implement protection upgrades and increases the likelihood of error. Additionally, layering of schemes in this manor increases the applicability of the standard by making it more flexible without modifying the standard. Through this

B. Physical Layout

The high level physical layouts for a 100kV line and for a 230kV or 525kV line standard schemes are shown in the figure below.

![Figure 1. Standard Panel Layouts](image)

On the 100kV standard, the primary and secondary protective devices are on the same panel, along with the manual trip/close device, and any other functional devices that the line may require. On the 230/525kV standard, the primary and secondary protective devices are split out onto separate panels. Each breaker has its own manual trip/close device as well as its own breaker failure and control relay, both of which are on the primary DC and primary CT circuit, and are therefore on the same panel as the primary protection. This allows the flexibility to handle breaker and a half, ring bus and double bus configurations. Any extra functionality associated with the primary or secondary protection is split out to the corresponding panels.

One important aspect of physical layout of the standard schemes is that only one piece of equipment, whether it be a line, bank or capacitor, will be on a given panel or panels. Previous standard packages utilized multiple lines per panel. The use of a single panel to house the protection for multiple lines creates issues in operation, maintenance and upgradeability. By limiting only one piece of equipment per a panel concerns about having to leave part of the panel hot for in-service equipment during maintenance activities are limited, making it easier to maintain and test the protection scheme. The drawback to this decision is that it requires more space in the control house; however the potential gains of having separate panels as described above outweigh the loss of control house space.

C. Standard Logic v. Stripping Logic

The utility power industry has identified a key contributor and source of line mis-operations and unexpected outages – relay settings errors. While those outside of the System Protection or Protection and Control groups think of
setting errors as being one big type of error, protection engineers know there is a difference between a “set-point” error and a “logic” error. Industry reports and statistics generally do not differentiate between the two. A large portion of these settings errors are logic errors. These can be greatly reduced or eliminated by removing the need to customize, develop, or strip unused logic out of a setting template.

Our approach to using production setting templates is simple – do not modify relay logic unless absolutely necessary. This practice allows the “Setting Engineer” (or “Relay Application Engineer”) to focus on the application; getting the modeling, calculations and set-points correct for the project. As a best practice, a new setting template should be thoroughly tested in the lab prior to implementation and installation in the field. In the same spirit, any modification to a production setting template should also be thoroughly tested prior to implementation. Unfortunately, this step is often skipped in order to quickly produce timely setting packages from the engineering organization.

Historically, a practice that was utilized was the “stripping of unused logic” from a production template based on the specific functionality that was needed for a given application. If there was functionality contained in a standard setting template that was not needed for the specific application, the unneeded logic was removed from the relay settings to be installed in the field. Every project could potentially lead to customized settings. The practice of stripping the logic was a significant source of logic errors and potential relay mis-operations if not fully tested while field commissioning.

A practice of developing standard setting templates that could cover multiple application differences without the need of stripping logic has been developed in recent years. Additional documents or drawings are used to guide field performers on what is and is not utilized in the standard logic template. Exact details of how this is done are outside of the scope of this paper.

The practice of utilizing a standard setting template that does not require site specific logic changes or modification leads to the next level of benefits; the “certification of logic templates” and the development of standardized pre-written automated test routines for field commissioning. Pre-written test routines allow the expediting of the testing and overall a significantly reduced commissioning time. Less experienced relay technicians can test the expected functionality of relays that use “certified logic templates”.

D. Minimizing Number of Settings Templates

One of the most challenging aspects of developing a production standard is managing all of the components and keeping them up to date as the standard matures. One of the components that can prove to be most difficult to maintain is the setting templates. The use of standardized setting templates is necessary to create consistent repeatable solutions with the goal of minimizing errors, design time and commissioning time. While the use of standardized settings templates is a necessity, minimizing the total number of settings templates is also very important. The reason for minimizing the number of settings templates is that each settings template has to be managed and maintained by the protection engineers and the engineering resources are often limited or overloaded.

Duke Carolinas West minimized the number of settings templates on the 230kV/525kV line protection package by using line protection relays that only contained line protection. Separate relays for breaker failure and control were used for each individual breaker. Previous schemes incorporated the breaker failure, breaker control, and reclosing into the line protection relays. The reclosing was only included in the primary or “A” relay and not in the secondary or “B” relay. Breaker failure was included in both relays. This meant that there had to be at least two settings templates for each different scheme. Also, the physical configuration of each station varied which meant that a standard settings template had to be created for breaker failure and reclosing of two breakers, breaker failure for two breakers and reclosing for one breaker, breaker failure for two breakers and no reclosing, etc. For instance, in an application with two lines, both with POTT scheme, in the same breaker and a half string, four separate settings templates had to be developed to accommodate the design. By choosing to make the line protection relays only contain line protection, a single settings template can be created for each type of line protection scheme (POTT, DCB, 87L, etc.), and then separate breaker failure and control templates (one with reclosing and one without). Even though the number of relays for the scheme increased, the number of settings templates decreased. The trade off in this case of using more relays to achieve fewer settings templates is acceptable due to the reduction of design, template management and application errors. Given the example discussed before (two lines in the breaker and a half string), the new standard protection and control package reduces the number of settings templates from four to two: a POTT template and a breaker failure and control with reclosing template. When considering all of the different options that could be encountered for a 230kV/525kV line, the total number of templates that need to be created and maintained can be reduced from more than twenty templates, down to five.

E. Common Look and Feel Across the Schemes

Creating a common look and feel across standard protection and control schemes is a desirable feature of the new standard protection and controls packages. The common look and feel addresses several of the areas of consideration discussed in the previous section. By establishing a consistent look to the protection package it reduces the likelihood of error from a human performance standpoint and makes operating and maintaining the system easier. In order to create the common look and feel across schemes during development, previous standard schemes were surveyed to attempt to incorporate the existing schemes, and maintain a level of familiarity. This eased in the transition from using the older standard to the new standard from both an engineering and field technician perspective. Also included in the creation
of a common look and feel was the utilization of the same pushbuttons, latches, timers, inputs and outputs across multiple schemes. This means that for a stepped-distance scheme and a POTT scheme and a DCB scheme the reclose blocking pushbutton is always in the same location, or that the trip coil monitor always uses the same timer. By doing this, it is possible to approach a scheme that is new to the user and come up to speed more quickly because it is similar to a scheme that the user is already familiar with.

Creating a common look and feel does not necessarily mean using only one manufacturer of relays. While using the same pushbuttons, latches, timers, etc. can really only be done with a single manufacturer, it is possible to apply the same connection and interface functions between multiple manufacturers. By using the same design parameters and concepts, it is possible to develop a scheme that uses different relays and maintains consistent functionality and interface.

**F. Limiting Types and Models of Relays**

One of the major considerations that Duke Energy Carolinas West took into account during the standard protection and control package development was limiting the types and models of relays. In the past, the relay type and model number was customized for each application or each different standard. This created the problem of having to stock multiple versions of the same relay type with slightly different configurations. This becomes an even bigger issue when replacing a failed relay in the middle of the night and getting the correct relay configuration the first time is very important. For instance, you could have the same type of relay with one version having extended I/O, and one version having pushbuttons and another not or even just different firmware versions. All of this variability creates a logistical nightmare and increases the workload of the protection engineer and the field technicians. Given these issues, it was decided to attempt to minimize the number of different models and types of relays. This means that the same relay model could be used for breaker failure and control, and for radial line protection, and for capacitor protection, where previously three different models would have been used. In order to accomplish the goal of limiting the number of different relays used, an evaluation of the each of the possible uses of the relay had to be done to ensure that the capability required by each scheme was incorporated into the selection of the relay model. An example of this type of thinking is ordering a line differential relay with both a fiber and a copper connection for the differential channels, thus allowing the same relay to be applied with both a fiber and a copper connection for the differential channels, thus allowing the same relay to be applied with either communication medium as opposed to have a different relay model for each case.

**G. Future Expansion and Modification**

Developing these new standards has exposed issues with previous designs’ abilities to be upgraded and modified. Often, the original intent of a job is to only replace one relay rather than an entire asset’s protection scheme. The way in which the older schemes were designed, replacing one piece of equipment at a time was effectively impossible. These standards were developed with the goal of being able to integrate with existing work (brownfield work) just as easily as being designed for a brand new station (greenfield). It was also desirable that our new standards be easy to upgrade and modify in the future so that we do not run into the same issues we experience now with replacing one piece of equipment at a time.

To meet this goal, it was first decided that inter-relay communication would be handled through copper contacts rather than through any specific communication protocol. In these standards, hardwired connections handle functions like reclose initiate, breaker failure initiate, breaker failure trip, direct transfer trip initiate, carrier start, and carrier stop. The use of hardwired connections allows any manufacturer’s relay of any vintage to communicate effectively with any other manufacturer’s relay of any vintage.

Second, it was decided to maintain the current practice of external lockouts for breaker failure, and external tripping relays for bus differential. Previous attempts to use a “daisy-chain” design for bus differential and breaker failure trips as a standard did not allow for installations in brownfield projects, which necessitated multiple standards, and increased the likelihood of human error in design. In addition, the “daisy-chains” caused significant testing and maintenance issues. Maintaining the external lockout and auxiliary tripping relays for breaker failure and bus differential applications allows much more flexibility in where a standard can be implemented by making it possible to implement the brand new design at either a brownfield or greenfield project. This, in turn, decreases the total number of standard designs. This decision also allows for greater flexibility with upgrades in later years.

On the 230/500kV standard, it was also decided to use an external breaker failure and control relay. Removing the breaker failure and reclosing applications from the protection relays allows for a higher level of standardization in the protection relays. In the future, this will allow the Duke Carolinas West to only replace the primary, or only replace the secondary, or only replace the breaker failure without having to disrupt the protection design for the rest of the asset.

**H. Lessons Learned From Previous Standards**

There are a number of lessons we have learned from previous production standards. While some of these were originally not an issue, over time there became a need to modify. A short discussion of each is given:

**Lesson learned #1** - Two transmission lines protection packages per a panel is not a good idea. Placing the protection packages for two lines on the same panel creates operational and maintenance challenges. This arrangement makes it difficult to isolate and work on one line while leaving the other line in service.

**Lesson learned #2** - Individual engineering preference leads to unmanageable standards. The practice of allowing engineers to customize the standard either by stripping logic or by choosing which logic elements are used leads to designs and templates that are not repeatable and do not have a common look and feel.
Lesson learned #3 - Simple layers of protection is preferable to complex condensation of protection. The practice of condensing all protection functions into fewer relays leads to designs that are not flexible and not repeatable. Layering simple protection schemes increases flexibility and decreases commissioning time and difficulty.

Lesson learned #4 - No reason to have separate HMI and non HMI templates and schemes. There is no reason to have multiple schemes that perform the same function when a single scheme can accommodate all options. Multiple schemes can lead to inconsistency and confusion in the application of the scheme as well as increasing the number of schemes that must be managed.

Lesson learned #5 - Training and development are aided by the development of standard schemes. Consistent application of standard schemes aids in the development of protection engineers. The common look and feel leads to a familiarity from scheme to scheme and decreases the amount of time required to become familiar with the scheme.

Lesson learned #6 - Deviating from standard schemes leaves you vulnerable to engineering errors and mis-operation. Tried and true, tested standard schemes have been vetted and the possibility for error is drastically reduced. Any deviation from the standard scheme introduces the possibility of human error, making the scheme more prone to mis-operate.

VII. CONCLUSION

The benefits of having production standards are well understood. In order to maximize these benefits, a rigorous examination of lessons learned (both good and bad), a thorough examination of the areas of consideration and the decision making process as outlined in this paper will be required. After going through this process, a clearer vision of where you want to be with production standards should evolve. Skipping steps or not giving sincere engineering thought to each of the decisions will result in a production standard of reduced usability and lowered repeatability. Too many cases of having to roll designs out the door in order to meet project deadlines only contributes to poor standard development.

As a good rule of thumb – simplicity is always good and repeatability is key to a good production standard. If a production standard can be used in many installations with very minimal changes, its development will benefit all parties involved in the capital project process. Customization and one of a kind designs will result in higher project costs, more complicated testing, require more troubleshooting and slower project execution. A good production standard takes time to develop and additional time to test and mature; time invested on the front end will save huge amounts of time later.

REFERENCES


AUTHORS

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