Best Practices for Developing and Implementing a New Protection Design Standard

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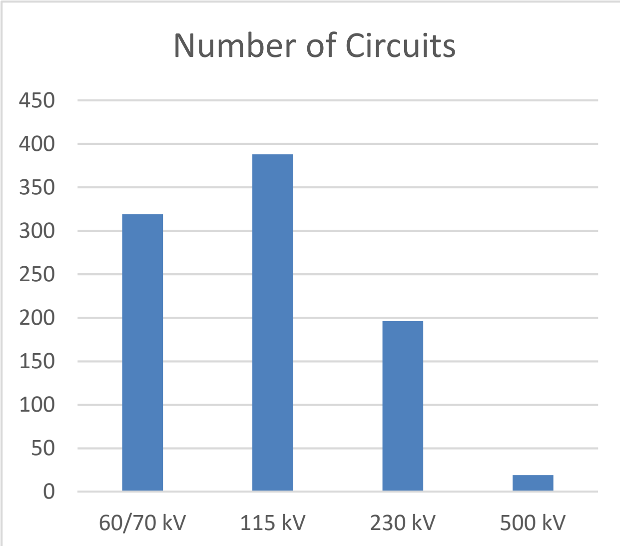
Abstract

Pacific Gas and Electric recently produced and implemented a new series of protection design standards. Painful lessons learned in previous standard rollouts taught us that issuing a new set of prints was not adequate. This paper discusses best practices in implementing new design standards. This latest standard is titled Sustainable Modular Protection (SMP) Standard. This integrated standard relies on a mix of DNP communication to the relays and a mix of relay pushbuttons and panel mounted control switches for local switching and remote visibility and control. The main categories that go into a best practice for creating and rolling out a new protection design standard are: (1) Relay Selection, (2) Prints, (3) Job Aids, (4) Training. Multiple issues under these four main areas are discussed. These include: Input from all stakeholder groups in development, building anticipation with stakeholders, testing and refining the standard before the first pilot project, identifying the best practices for job aides and setting aids, creating one standard that will apply to multiple configurations and protection schemes while limiting the number of products used, sustainability (design with lifecycle replacement in mind), simplicity (design for journey level skill set), and developing training for multiple work groups. Testing before our first pilot project resulted in multiple logic and setting changes and some minor wiring and panel changes. All of this work during the development of the standard and during rollout resulted in very few issues in the field and satisfied user groups.

I. Introduction

Pacific Gas and Electric

Pacific Gas and Electric (PG&E) is an investor owned vertically integrated electric and gas utility serving most of northern and central California. PG&E has 5.4 million electric accounts and serves a population of approximately 16 million. The asset base at PG&E includes 107,000 circuit miles of overhead and underground electric distribution lines; 18,443 circuit miles of electric transmission operating at 500 kV to 60kV, 2.4 million distribution poles, 3,200 feeders, 140,000 transmission structures and more than 7,000 MW of company owned generation.



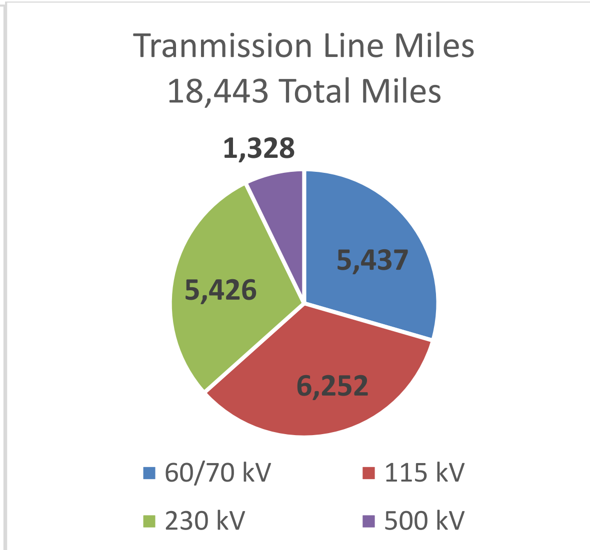


Figure 1 - Number of Transmission Circuits and Mile of Transmission Lines by Voltage

The transmission system is made up of more than 900 circuits (Figure1). Our relay fleet includes about 34,000 relays at the transmission and distribution level. The 500 kV system utilizes its own protective relay design due to unique requirements of series compensated lines and the need for high speed fault clearing at all times. The 60, 70, 115 and 230 kV systems follow the same group of design standards that in the past varied considerably for different bus configurations and for line current differential applications.

This paper will discuss best practices to develop and implement a new protective relaying design standard by using our recent development of a new set of design standards. The new Sustainable Modular Protection standard or SMP standard took a great deal of time, money and labor to develop. Some of these same best practices can be applied with reduced effort while still producing the same deliverables. This will be contrasted with our lessons learned and shortcomings of our previous relay standard. The previous Integrated Protection and Control Standard (IPAC) was used for 12 years and met very stringent design requirements.

II. Background

How Not to Roll out a Standard – Bad Experiences

In 2004 PG&E rolled out its first Integrated Protection and Control (IPAC) standards. These design standards integrated the SCADA, metering, and most control functions within the protective relays. Relay pushbuttons were utilized to minimize the use of traditional control switches. Much of what used to be hard wired was converted to relay logic. For the protection engineer, relay tech, and design engineer, these new standards were a leap in technology and required a steep learning curve.

Unfortunately, the new standards were prematurely deployed due to pressure from upper management to implement a new Modular Protection and Control (MPAC) drop in place control building strategy and the new IPAC standards were a key to this. New projects were required to specify the IPAC standard before it was even completed. Minimal testing was performed on the IPAC standard prior to actual project implementation. Multiple projects were being designed and constructed in parallel, a shot-gun deployment. Struggles surfaced when the first several MPAC control buildings with the new IPAC standard were being tested at the factory with the unproven relay logic and designs. Errors in relay logic required engineers and technicians to learn a new skill set to trouble shoot and fix problems. Some problems were fixed at the factory, but many were not and had to later be fixed in the field on multiple projects. Due to the premature deployment of the standard, not all jobs aids were completed, and little training had been done, which contributed to the struggles in the field.

How Not to Roll out a Standard

- Narrow stakeholder input
- Untested before deploying
- Shot-gun deployment
- Push relay to its limits
- Little or no training
- Incomplete job aids
- Rigid inflexible standard
- Manufacturer dependent
- Create interdependencies between relays
- Requires advanced skillset

Early adoption of technology also created challenges. Multiple relay firmware upgrades had to be performed in the field as bugs were found in the relays. Additionally, narrow stakeholder input while the standard was being developed resulted in some key features being left out of the standard, such as the ability to cut out Line Test or High Speed Reclose from SCADA. These key features and firmware upgrades were later required to be added to approximately 600 relays already deployed and in service with the IPAC standard at considerable expense.

Learn from our Mistakes

"Anyone who has never made a mistake has never tried anything new."

Albert Einstein

Relay dependencies between the Set A and Set B IPAC relays also created complications. Some functions were segregated between Set A and Set B in a master/slave relationship. The old IPAC design resulted in complete dependency between the exact relays used so a single relay replacement with a different product is not possible. Additionally, manufacturer specific GOOSE messaging was used between relays in BAAH and Ring Bus designs. This made replacing the Set A relays with a different product not possible and introduced additional complexity that required a new advanced skill set for the protection engineer and relay technician.

Rigid bus and scheme specific IPAC standards required so many prints, logic diagrams, relay templates and associated job aids, that keeping them all up to date became very burdensome which contributed to stagnant and out of date prints and job aids.

Benefits of having a good standard

SMP Change Drivers

- *Simpler*
- *Sustainable*
- *Flexible*

The driver for the new SMP standards development was to learn from and correct know issues and deficiencies with the prior IPAC standards. Striving for a new standard that would be:

- **Simpler** - For design, protection and automation, and testing and commissioning
- **Sustainable** – Not vendor specific, and supports life cycle replacements
- **Flexible** - Not bus configuration specific, utilizing building block approach

The benefits of having a good standard include:

- Standardization/familiarity – Same design applied over and over.
- Cost savings – Reduced engineering and construction/test labor.
- Ease of application – Building block approach. Flexible design that can be used on different bus configurations or enables converting bus arrangement without replacing relays.
- Sustainable design - Enables relay life cycle management (e.g. 1 for 1 relay replacement) if standard is developed with that in mind. Conversion of bus, etc.
- Ability to perfect over time – Employ continuous improvement.
- Reliability - Reduced complexity resulting in reduced work procedure errors. Use of relay setting templates and job aids reduces setting errors. Use of reliable relay vendor resulting in fewer relay failures and misoperations.
- Compliance – Alignment with NERC standards.

III. Management and Stakeholders

Like most large companies we have a standards group, review committees, and must get management approval before spending money on a new design standard. In parallel with our relay selection we started meetings with our stakeholders to create a high-level scope about the new design, the cost to create and test the new standard and the benefits of the new standard. We then created presentations for our Vice President to obtain formal approval to start work on a new protection design standard. During the job estimate approval process, we were questioned about the cost savings and payback period for the cost to create new standards. Whatever the structure and politics of an individual company these approvals and buy ins must be done before developing a new design standard.

It is hard to show cost savings for a new protective design standard. In many cases standards are changed because relays or components are no longer available or relays with significantly improved features are available. In our opinion design standards based on specific relay models should be reviewed or updated within 8 years or less. The driving factor to create the SMP standard was that our IPAC standard design was not sustainable. The method used to integrate SCADA onto the two different relays did not allow the scheme to be operated with a single relay in service and a failed relay had to be replaced with the same relay or the entire terminal had to be replaced. There was no viable relay end of life replacement option other than a complete terminal replacement.

We included individuals from Automation Engineering, Test Department and Operations in the development team from the beginning. It can be difficult to get the necessary time commitments from these groups, but it is key to getting their input in developing a standard that has benefits for these groups and it helps ensure a positive reception to the new design. Many design improvements were made to reduce the work and risk of a human performance error for our technicians. We reduced our SCADA DNP point list from our previous design by about 75%. We made improvements that allow switchmen to easily assess station conditions when they enter the control building. Some of the changes in the new standard created additional steps for operations and design engineers but there were enough overall benefits that the collective decision was to implement the changes.

Figure 2 - FT Switches with Individual Labels and Lighted Pushbutton showing Breaker Status

A few of the changes that stakeholders requested during testing were to have our FT switch vendor supply standardized labels pre-installed on each switch handle and the use of large lighted breaker control pushbuttons that show breaker status easily from a distance. See Figure 2. Other changes included the addition of one rack unit spacer panels to aid in testing, changing stub bus setup from multiple relay pushbuttons to a single control switch to simplify switching and lowering the current shorting switches to improve ergonomics.

An additional strategy that proved valuable was to build a sense of anticipation for the new standards. Most people resist change because they are accustomed to the status quo. To overcome this, we provided regular updates to many client groups. This was done through many presentations at team meetings where we highlighted the benefits in the standard for that group. We also discussed timelines for the new standard and the extensive validation testing that we were doing to ensure a smooth rollout.

IV. Design Decisions

1. RELAY SELECTION - SINGLE MANUFACTURER

There were many design decisions that were made to simplify the SMP standard and meet the objectives of the standards team and stakeholders. The most controversial decision was going with a single relay manufacturer and using identical relays for both Set A and Set B protective relays.

Some of the reasons for this decision were:

- Higher reliability – The selected relay manufacturer had the best performance at PG&E as well as in surveys for North American utilities. Internal relay failure tracking as well as vendor provided statistics showed the selected relay manufacturer to be a more reliable product.
- Simplifies, design, testing, training and interdependencies.
- High level of confidence in the integrity of hardware and firmware for present generation of relays compared to early microprocessor relays.

It was recognized that a single manufacturer increases additional risks of common mode failure, but the increased risk is very small and more than offset by using more reliable relays with a simpler design. Two other peer utilities in WECC were found to have used two identical relays for their existing standards for more than 15 years with no negative outcome. There were no known cases of two common mode failures at the same time. A recent North American utility survey was also referenced showing use of two relays from the same manufacturer and even the same model was not an uncommon practice. Multiple conference papers have been written on single manufacturer and fault tree analysis that outline the risks of single manufacturer and how to manage them. For PG&E it was felt that a single manufacturer design would be more reliable, and risks were minimized by going with a relay manufacturer that was highly reliable, proactive in providing relay advisories and corrective actions, and provided excellent support.

2. BUILDING BLOCK APPROACH – UNIVERSAL BREAKER CONTROL AND PROTECTION PANELS

A common standard was developed for all line protection, transformer protection, and breaker control panels that could be applied regardless of bus configuration.

- This minimizes the number of standards, setting templates, test procedures, description of operations and training documentation.

- Design unbundles the protection function from the breaker control and breaker fail function. This requires additional relay panels for DBSB design but enables bus configuration changes without complete building replacement. Also results in less relay interdependency and significantly simpler design.

- Sustainable design – The unbundled design will allow single or double relay replacement. Existing MPAC design results in complete dependency between the exact relays used that single relay replacement with a different product is not possible.

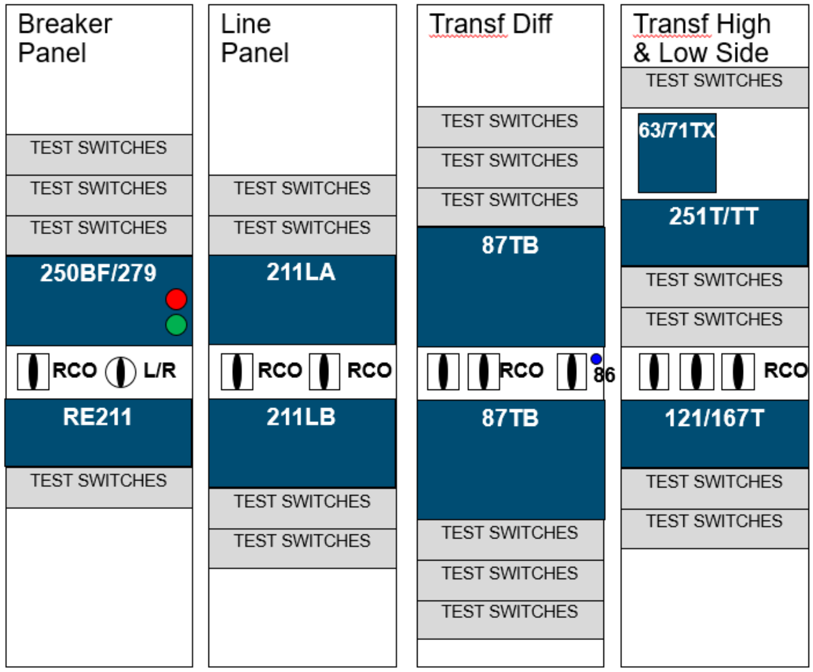


Figure 3 - SMP Standard Panels

3. UNIVERSAL LINE PROTECTION

For line protection it was decided to standardize on two identical line current differential relays, and only have one relay standard using these relays for 230 kV to 60 kV. The relay standard could be applied for all scheme types (non-pilot, current differential, POTT, or blocking) utilizing any communication media (digital, analog, or power line carrier). This required spending more on the cost of the relays, but were offset by efficiencies captured in setting, testing, design, training and operations. The risk of common setting error can be mitigated by peer setting review process and thorough testing processes. Overall, we feel setting errors will be reduced with two identical relays applied as part of a universal line protection standard.

4. CONTROL SWITCHES vs RELAY PUSHBUTTONS

There were many decisions on relay pushbuttons versus control switches for controlling various relay features. On the prior IPAC standards, relay control switches were minimized as much as possible and instead relay pushbuttons were used. Some of these functions included the breaker open and close, relay setting group selection, pilot enable, high speed reclosing enable, line test enable, breaker failure lockout (latch in relay with pushbutton for reset), Local/Remote (for supervising SCADA control), and relay cut out (RCO) which supervises the relay trip outputs.

A balance point had to be found. In general, System Protection and the Test Department were for utilizing more physical control switches to simplify relay logic and design, and to provide better relay isolation with an RCO switch for disabling the relay trips when the relay was in alarm or cleared for maintenance testing. System Automation on the other hand preferred more use of pushbuttons which facilitated easier implementation of SCADA control for various functions. In the end it was decided that if a relay function resided solely within one relay, then use of the relay pushbutton was a good application.

For example, on the Set A and Set B line protection relays each relay has its own pushbutton for pilot enable and up to six pushbuttons for setting group selection. The Set A and Set B relays are redundant and completely independent of each other. The pushbutton controls on one relay does not affect any other.

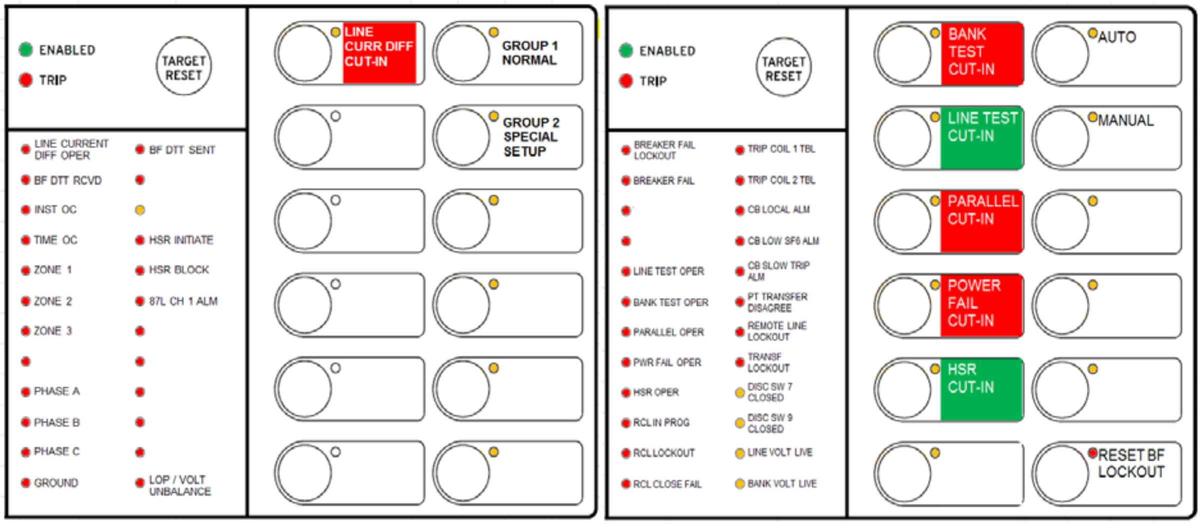


Figure 4 **Line Relay Pushbutton and LEDs** **Breaker Failure/Reclosing Relay Pushbutton and LEDs**

Following are the functions that physical rotary switches were installed for:

Relay Cut Out (RCO) Rotary Switch (SCADA Operable)

- One RCO switch per relay. Requested by techs and protection engineers. Relay cut out needs to be external to relay being cut out. Simplifies setting and testing.
- SCADA operable to allow remotely cutting out suspect or failed relay.
- Allows cutting out relays from HMI instead of at front of panel.

Local/Remote Rotary Switch (Not SCADA Operable)

- One Local/Remote switch per breaker panel. Requested by maintenance and construction to block remote operation of devices. Supervises SCADA control for relays on breaker panel, as well as for adjacent line or transformer panel(s). For BAAH or Ring Bus, if both breakers for a line or transformer terminal are in Local then SCADA is disabled for the line or transformer relays.

Stub Bus Protection Enable Rotary Switch (Not SCADA Operable)

- One switch per line or transformer terminal. For a transmission transformer there may be a stub bus enable switch for both the high side and low side terminals. Switch enables stub bus protection mode on the line or transformer relays for that terminal, and provides status to the breaker failure/reclosing relays on adjacent relay panels to disable reclosing.

- Stub bus enable switch is compared with pallet contact from line or transformer high voltage disconnect switch in the line or transformer relays and a discrepancy alarm asserts if the two are not in agreement.

- For SMP standards the pallet contacts from high voltage disconnect switches are only used for status or alarm and are not used to control the relay protection. The reliability of the pallet contacts is questionable for providing accurate status.

Potential Transfer Rotary Switch (Not SCADA Operable)

- For some double-bus single-breaker bus configurations, 3-phase bus potentials from either bus 1 or bus 2 are used to provide potential to the line protection relays. The potential transfer switch selects which potentials (bus 1 or bus 2) are provided to the relays.

5. AUXILIARY RELAYS

Auxiliary relays are not applied on SMP standards. Auxiliary relays are becoming fewer on the market and have long lead times. They are normally electromechanical devices and have no self-monitoring, so extended maintenance intervals cannot be applied per PRC-005-6. Microprocessor relays can now be ordered with a large number of relay contact outputs and the use of auxiliary relays can be avoided.

6. IEC61850

The use of IEC61850 was not applied on SMP standards. This was done to keep relay settings/logic and associated relay testing simple and at a journey level skill set. Tools for configuration of IEC6180 in relay settings are not yet at the plug and play point and require advanced knowledge and skill set.

Additionally, the use of manufacturer specific communication protocols for direct (serial) relay to relay digital communication was not applied between relays within the substation. The main reason for this was to keep the SMP standards manufacturer independent, and also to allow interfacing with older generation relays for retrofit applications in existing substations.

7. DUAL TRIP COILS

PG&E Asset Strategy decided several years ago that all transmission breakers will be purchased with dual trip coils to match industry standards. Most breakers rated 230 kV to 60 kV still have a single trip coil. Previous protection standards were all based on a single trip coil. The SMP standards are designed to accommodate dual trip coil and single trip coil breakers. For simplicity, trip coil 2 is only wired to breaker failure retrip on the SMP standard. The individual relay trip outputs are wired to trip coil 1 and to initiate breaker failure. Since all protective relays that trip via trip coil 1 also initiate breaker failure, it is sufficient to just wire the breaker failure retrip to trip coil 2. If only a single trip coil is available, then breaker failure retrip is wired to trip coil 1.

V. Validate and Test Design (V&T)

In order not to repeat the mistakes of the past, the standard development team believed having a test bed to install and test the new SMP standard panels prior to deployment was a key step.

A retired modular control building in an existing substation was repurposed for use as the SMP validation and test (V&T) lab. This facility is also used as a training tool for operators and technicians.

It should be noted that the retired modular control building used for the SMP V&T was one of PG&E’s first drop in place control building projects using PG&E’s first generation integrated protection and control (IPAC) standards. The IPAC standards were bus configuration specific and the initial install at this substation was on a 115kV double-bus single-breaker (DBSB) bus configuration. A few years later the 115kV bus was replaced with a new breaker-and-a-half (BAAH) bus. The IPAC relay panels in the existing DBSB drop in place control building could not be repurposed for the new BAAH bus due to the rigid IPAC design and a new control building was installed and the old control building retired and left on site.

Figure 5 - Drop in place control building (IPAC or SMP)

For the V&T, it was decided to build and install test panels for a 230kV BAAH bay with one line and one 230/115kV transformer. The panel arrangement consists of 3 breaker panels, 1 line panel, and 2 transformer panels. Since the V&T panels are not wired to any high voltage circuit breakers, breaker simulator relays were also added to the bottom of each breaker panel. The V&T building also includes an HMI computer to facilitate testing of SCADA/HMI screens and functionality.

Figure 6 - SMP validation and test control room

Later, in phase 2 of the SMP standard development, additional panels were added to the V&T building for a 115/12kV distribution transformer with high side breaker and low side double-bus double-breaker switchgear panels.

The V&T proved valuable in testing the relay logic, SCADA, and in fine tuning the initial design. Some of the items found and addressed included, (1) an issue with how the breaker close pushbutton and relay sync check were defeating the breaker anti-pump, (2) moving stub-bus protection enable function off of multiple relay pushbuttons to a single rotary switch for a simpler operator interface, (3) swapping of some relay FT switch assemblies, so that the FT switches for the currents were not at the top of the switch rack to make inserting the current test spades easier, (4) adding some additional 1 rack unit blank panels between rotary switches and the relays where spacing was inadequate for wiring on the rear side of the panel.

Feedback was solicited on the physical layout of relays, switches, terminal blocks, and also on the relay pushbutton and LED labels and relay FT switch lamacoids (See **Figure 2**). Several layout issues were found during testing. An issue found on the line panel that only occurred when adding an optional power line carrier transceiver to the top of the panel. It obstructed some of the terminal blocks on the rear wing panels. The line panel for the V&T was initially configured for the more common digital line current differential or digital POTT application, however during the V&T testing it was decided to add the power line carrier transceiver to test that application, which revealed the issue with the wing panel terminal blocks. The wiring on the obstructed terminal blocks was relocated and the obstructed terminals were spared out.

The functionality of the universal line template was tested during the V&T. A single relay template is applied for 230 to 60 kV for all schemes (Current Differential, Digital POTT, Power Line Carrier POTT, Power Line Carrier Block, Non-Pilot) and logic bits are used to select the scheme type and bus configuration, reference **Figure 7** below. The logic bits enable or disable groups of logic depending on the scheme selected. The standard relay logic is not modified.

```
# ========================== USER INPUT SECTION ==========================
#
# ======================== 87L / PILOT SCHEME SELECTION ===================== ===
#
ASV001 := 0 # 87L ENABLE                    SET TO 1 IF DIFFERENTIAL PROTECTION IS TO BE ENABLED
ASV002 := 0 # POTT (MIRRORED BIT) ENABLE    SET TO 1 IF POTT PROTECTION USING MIRRORED BITS IS TO BE ENABLED
ASV003 := 0 # POTT (PLC) ENABLE             SET TO 1 IF POTT PROTECTION USING PLC/EXTERNAL COMM IS TO BE ENABLED
ASV004 := 0 # DCB   (PLC) ENABLE            SET TO 1 IF DCB PROTECTION IS TO BE ENABLED
ASV005 := 0 # 3-TERMINAL ENABLE             SET TO 1 FOR 3-TERMINAL APPLICATION FOR 87L OR POTT
ASV006 := 0 # HSR ENABLE                    SET TO 1 TO ENABLE HSR FOR 87L OR POTT OR BLOCK
#
# ======================== SETTING GROUP SELECTION =========================
#
# GROUP 1 AND GROUP 2 PUSHBUTTONS NORMALLY ENABLED - GROUP 1 (NORMAL) AND GROUP 2 (SPECIAL SETUP)
#
ASV009 := 0 # GROUP 3 PUSHBUTTON ENABLED
ASV010 := 0 # GROUP 4 PUSHBUTTON ENABLED
ASV011 := 0 # GROUP 5 PUSHBUTTON ENABLED
ASV012 := 0 # GROUP 6 PUSHBUTTON ENABLED
#
#= ======================== BUS CONFIG / STUB BUS ============================ ==
#
ASV014 := 0 # BAAH/RING ENABLE            SET TO 1 IF CONFIG IS TWO BREAKERS, I.E. BAAH/RING. SET TO 0 IF CONFIG IS SINGLE BREAKER
ASV015 := 0 # STUB BUS ENABLE             SET TO 1 IF DISCONNECT SWITCH IS AVAILABLE TO ENABLE STUB BUS LOGIC FOR BAAH/RING.
#
# ==================================================================
#
# WHEN ALL ASVS ABOVE ARE SET TO ZERO, RELAY SETTING TEMPLATE DEFAULTS TO NON-PILOT SINGLE BREAKER APPLICATIONS
#
## END ##
```

Figure 7 - Relay settings scheme selection (logic bit selection)

VI. Prints

One of the problems with our IPAC standards was that there were too many standard prints. We had a different set of design standards for Double Bus Single Breaker than for Breaker and a Half (BAAH) /Ring Bus. We applied a different design for the outside breakers on a BAAH than for the center breaker. We had one design standard for line current differential and another for POTT, Block and non pilot schemes. There were so many standard prints and setting templates that it became very difficult to maintain them all. This led to a decision to create a single high level standard composed of three different modules. A breaker module, a line protection module and a transmission transformer module.

Our goal was to create one set of standards that could be applied to any bus design, all line protection schemes and transmission transformers that are made up of single phase units or a three phase unit, with or without LTC's. Creating a single high level standard required many changes to our print format and to the types of standard prints that we used in the past. When we included our substation design group in this effort, we had to force them to look at design standards differently. Standards are not to make it easier for substation design engineers to do their job, they need to make it better for personnel to wire, test, and troubleshoot protection schemes in the field.

Previous design standards were created to match the prints issued for projects. The SMP standards include several prints that are not issued with project drawings. Some of these print types are detailed below.

We utilized design detail sheets that contained multiple detail sections that could be copied and pasted into the base schematics drawings depending on the application. We included options and instructions to detail applying the design to breakers with dual trip coils but also to older breakers with a single trip coil. Relay contact development tables were made that included all design options and added instructions to mark any that were not used on a specific project. We also made several changes to make the new standards easier to use for field personnel.

Two Reference sheets were included with the SMP standards. The first one shown in Figure 8, lists all the prints by a numerical list and by the three modules or panel types. This saves an enormous amount of time for everyone trying to find one of the prints in this group of standards. This was never done for protection standards before this. If someone can find this first reference sheet, they can find any print.

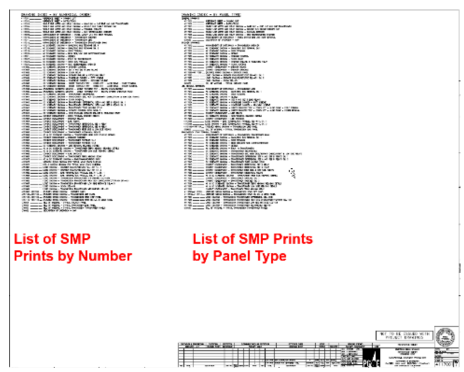


Figure 8-Reference Sheet 1

The second reference sheet details the "S" and "T" side of each breaker and the CB1 and CB 2 side of each line. These naming references are needed due to the building block standard which can be applied with a single breaker or two breakers and varying equipment layouts. This sheet also includes the DC circuit layout requirements and drafting instructions on finding and replacing standard codes with panel numbers and operating numbers.

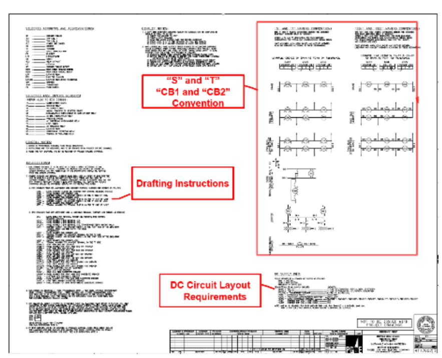


Figure 9 - Reference Sheet 2

Previous Design Standards were created to match issued project drawings. To create these modular high level standards, several prints were created that are not intended to be issued on projects. The block in Figure 10 was added to these prints.

NOT TO BE ISSUED WITH
PROJECT DRAWINGS

Figure 10 - Not to be issued with project drawings

Detailed Switchrack Arrangement Standards were created which also detail the side panels. Nameplate templates are called out and tied to the Bill of Materials Template. The side panel details include numbered terminal blocks and CT shorting blocks/switches as required. When designers copy and paste this rack layout for a project, the design software automatically puts <u>all</u> of the material items into a Bill of Material project drawing. This has dramatically increased the efficieny of our design process.

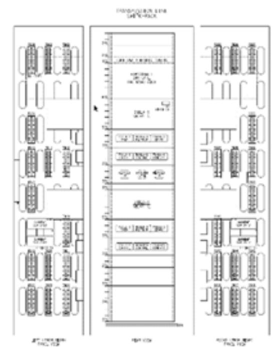


Figure 11 - Switchrack Arrangement Standard

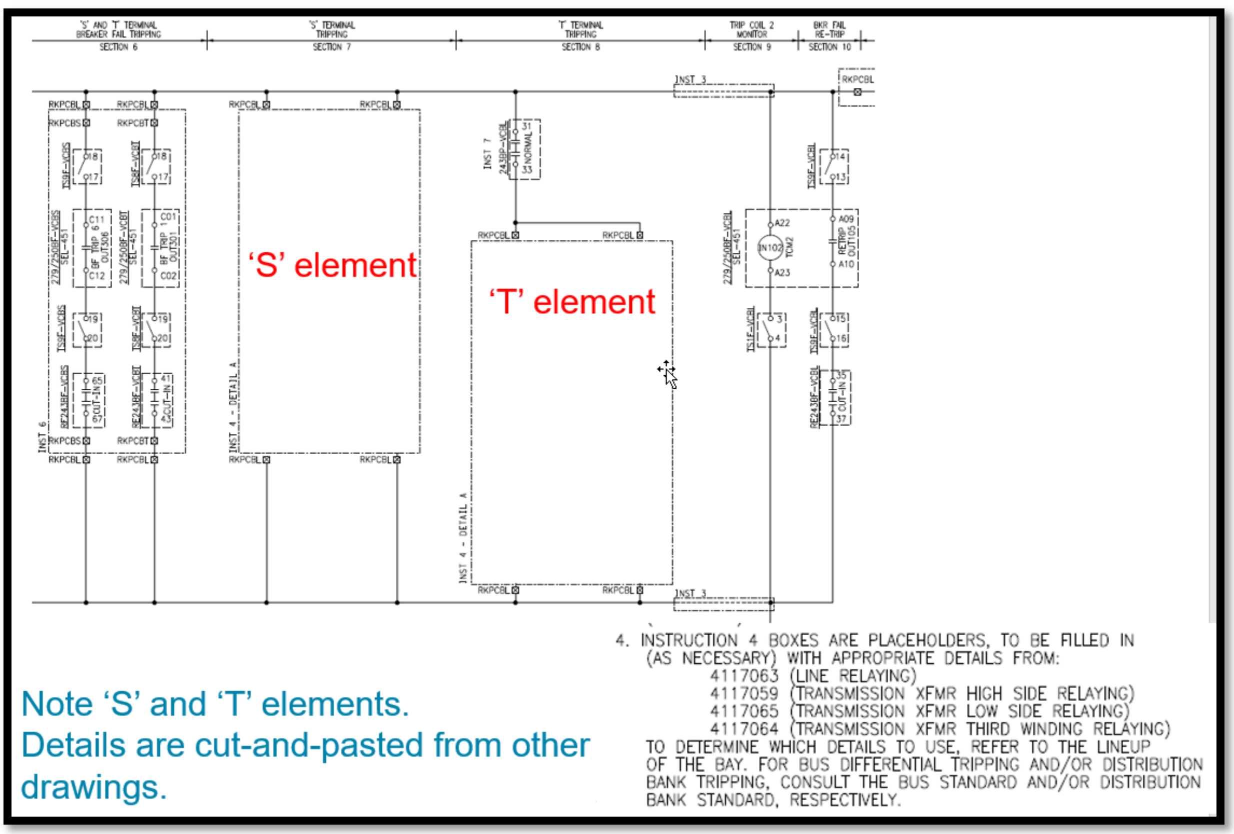


Figure 12 - The Modular Standard with detail placeholder

The high level modular standards require detail placeholders as shown in Figure 12 above. Since a breaker in a BAAH design can be adjacent to a bus, line or bank, these placeholders are shown with instructions for the designers to add details from separate detail sheets that are also part of the design standards. Our designers initially asked for standards that show all outdoor equipment combinations possible for a breaker (i.e. Bus -Line, Line-Bank, Bank- Bus, etc.) so that they could copy and paste into project drawings. Including all of these combinations would require ten times the number of breaker standard drawings.

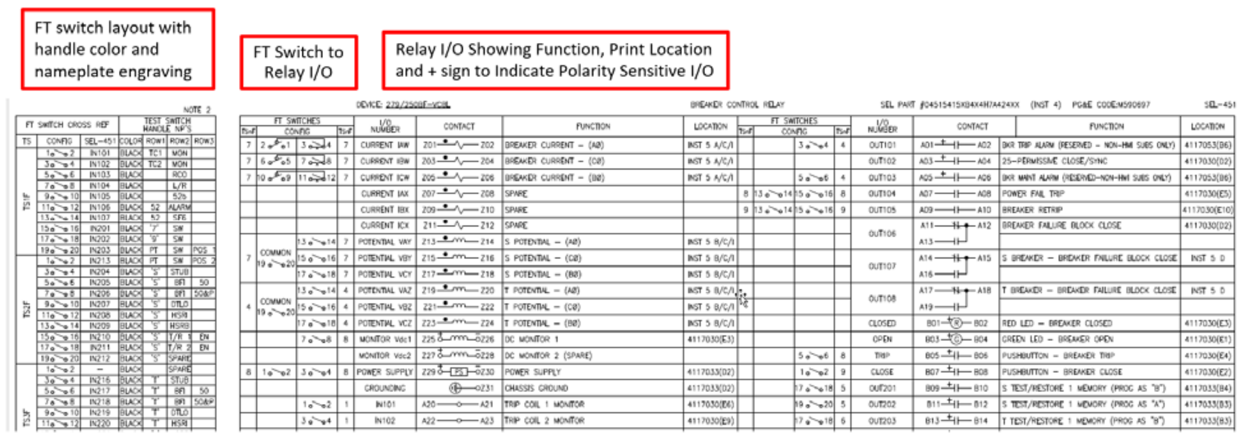


Figure 13 - Contact Development Print with new Elements

Past Protection Design Standards included a relay contact development table that showed the relay inputs and outputs. Due to feedback from technicians, this print was significantly changed. See Figure 13. The section on the far right is an FT switch layout view that shows the individual handle colors and the nameplate engraving that is inserted into each handle. These are shipped from the manufacturer with the nameplates engraved and installed. This ensures consistent abbreviations are used and acts as a safety check for technicians when testing relays. The next section shows the FT assignment for each relay I/O element. Showing the individual FT switches twice enables a technician to check each FT blade or check each relay I/O for proper clearance. The next section shows the relay I/O, what it is used for and where it is used on the print. A + sign was added to the polarity sensitive inputs after some problems were encountered with high speed output contacts. These prints are modified and issued for each relay on a project. Instructions are included to mark unused switch and add unused to each I/O that is not needed for a particular application.

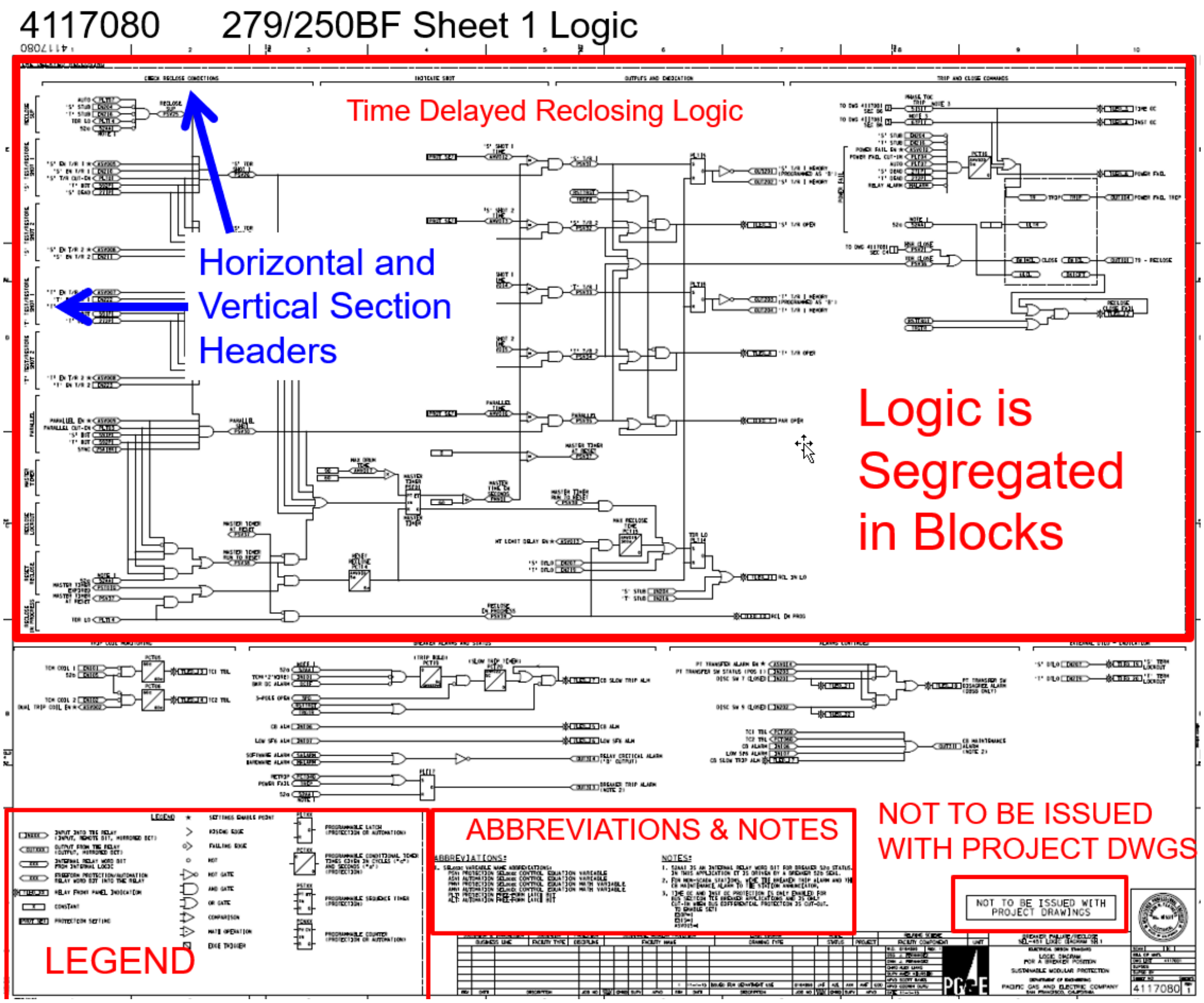


Figure 14 - Sample Logic Diagram

With the use of ASV logic bits to enable or disable blocks of logic and relay outputs, a standard logic diagram could be created within the design standards. One or two logic diagrams are created for each relay. This diagram is not customized and issued for projects as it would require too many print changes. Logical changes are simply made by changing a bit which is easy to view in the setting file and with the comments in the setting files it can instantly be determined which blocks of logic are enabled. Legend sections are included on each diagram and all sections are labeled to aid users.

A Cabling Diagram is part of the design standards to show how relays are connected for remote access, SCADA control and IRIG B time signal distribution.

The Bill of Material drawing includes all elements included on rack, including the rack itself, spacers and ground bars. Past standards only showed relays, meters and some switches.

VII. Job Aids

Job aids were created to aid in creating settings for the SMP relays and to aid in testing and trouble shooting. At the top of this list is standard logic diagrams.

1. STANDARD LOGIC DIAGRAMS

Logic diagrams create a visual aid for understanding the relay schemes and for trouble shooting the relay logic when something is not working properly (See Figure 14). On PG&E's prior IPAC standards, it was recognized that logic diagrams were needed for integrated relay schemes that were logic intensive. This was carried over to the SMP standards. For both sets of standards, logic diagrams were created with the design standard to match the base setting templates. Logic diagrams were not created for each project. The challenge with the IPAC standard was that there were so many different templates and logic diagrams that it was difficult to keep the logic diagrams up to date. Part of this challenge was that the setting templates were maintained by System Protection, and the logic diagrams were CAD drawings that were updated much less frequently by Design Engineers in the standards group. Also, as the IPAC standard evolved over the years and relay logic was modified, there was no way to correlate the revisions of settings/logic against the logic diagram.

Several things were done to help keep the SMP logic diagrams accurate, up to date, and to create the ability to cross reference the version of logic that a relay setting file was based on. The first of these was to minimize the number of relay setting templates. For example, by having only one universal SMP line relay setting template it is much easier to keep the template and logic diagram up to date and in sync when changes are required. By contrast, the prior IPAC standards had 12 line relay setting templates since a separate template was require for each scheme and bus configuration (Non-pilot, Current Differential, POTT, Block) x (DBSB or BAAH or Ring Bus). The next thing that was done was to track the logic diagram revision within associated the relay setting template and issued setting files. This is discussed in detail later in this paper in ***Template Revision Tracking*** section.

2. RELAY SETTING TEMPLATES

A single relay setting template was created for each relay on the SMP standard. The setting template provides a boiler plate for creating new relay settings. It promotes standardization of the setting files, creates efficiencies, and reduces errors. For each new project the protection engineer downloads the latest setting template posted to ensure the current and latest setting template is applied with the current approved firmware version.

Template Minimization

To minimize the number of setting templates a universal template approach was applied for the line, breaker, and transformer panels. Each setting template was setup to work for single or dual-breaker (i.e., BAAH or Ring Bus) to handle multiple bus configurations. Additionally, the line template was setup to accommodate any scheme applied at PG&E (Non-pilot, Current Differential, POTT, Block) as well as any communication media (Digital, Analog, or Power Line Carrier). To realize this capability, logic enable bits are used to make scheme and bus configuration selections. The logic enable bits enable or disable portions of the standard logic within the relay. The universal setting template contains standard logic for all configurations.

3. EXCEL RESOURCE GUIDE

A job aid probably unique to PG&E is what we call the resource guide. It is an Excel spreadsheet that maps out the various elements within the relay and how they are applied or assigned. A separate tab is used for each setting type, such as Latches, Logic Variables, Contact Inputs, Contact Outputs, etc. A standard resource guide was created for each relay setting template and is issued with the relay settings. The resource guide is a tool to help the protection engineer configure the relay setting settings and it is intended to be filled out as a first step before creating the relay settings.

The first tab of the resource guide is used to select the relay scheme options and bus configuration. From these selections, the resource guide lists the configuration of the logic enable bits, and auto updates several other tabs such as the pushbutton and LED configuration and associated tab for printing the pushbutton/LED labels. The tab with the pushbutton and LED configuration shows how the relay front panel will be configured and is used by the automation engineer/SCADA specialist to configure the SCADA and HMI relay target screens. The resource guide is also used by the relay technician for printing the pushbutton/LED labels and as a job aid for testing.

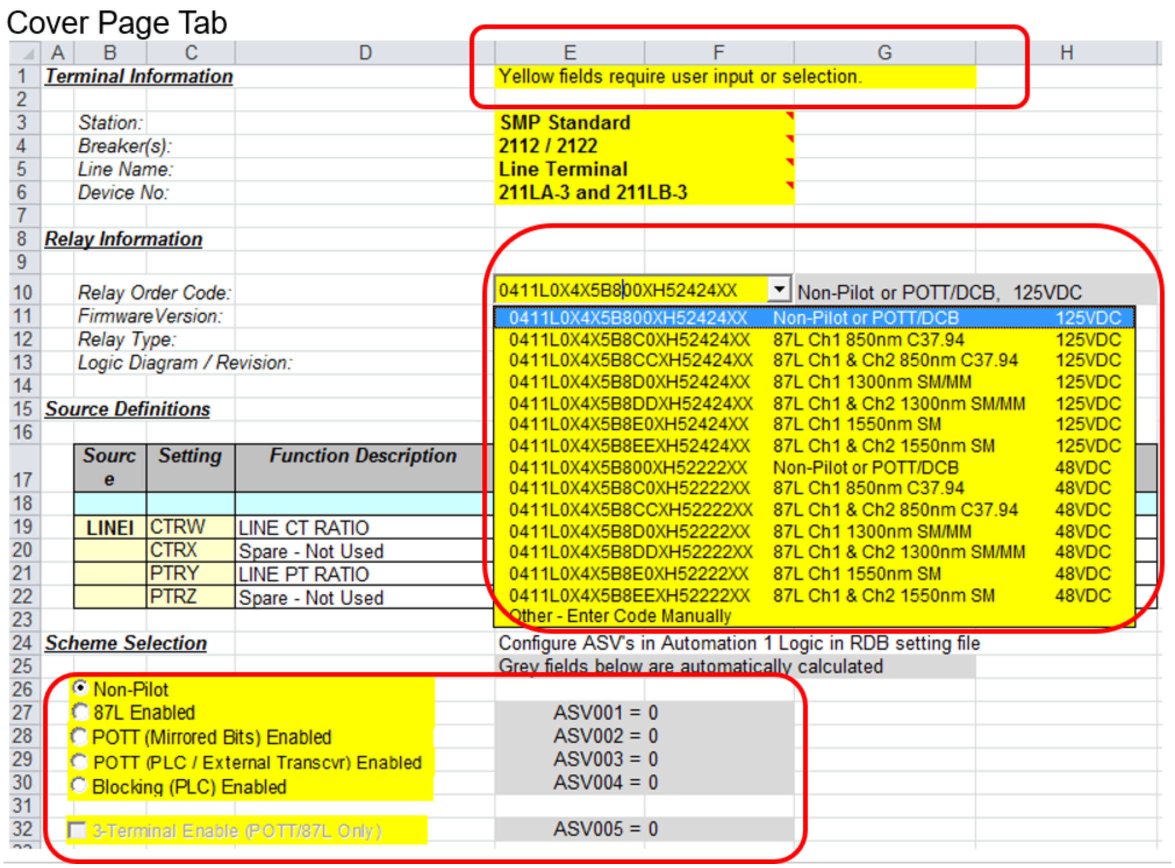


Figure 15 - Excel Resource Guide Cover Page Tab

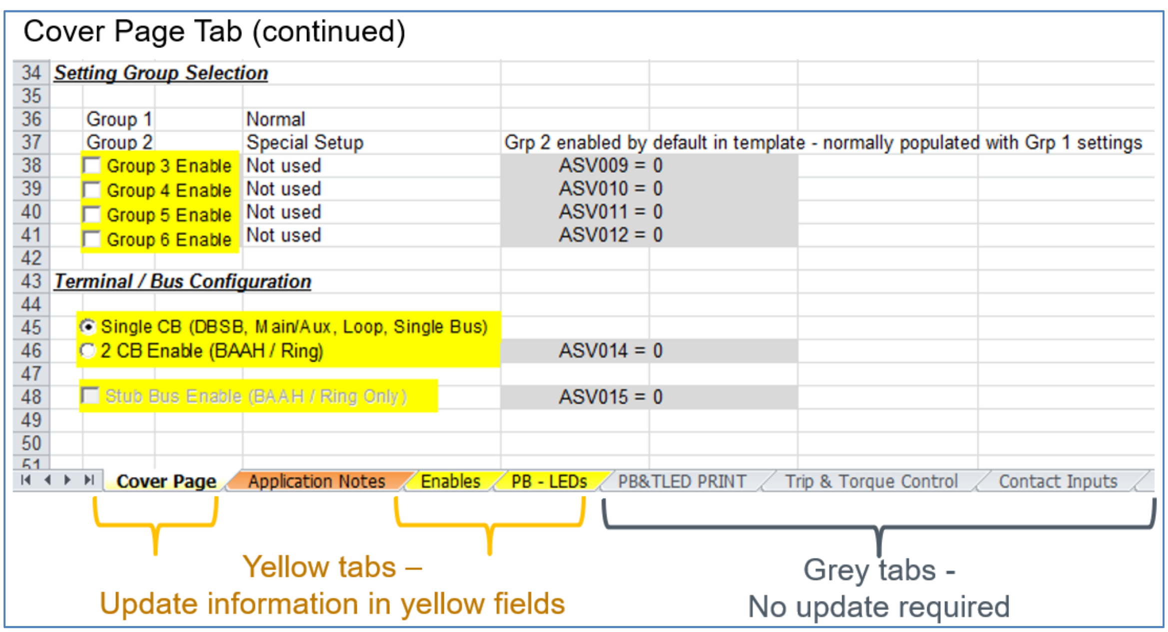


Figure 16 - Excel Resource Guide Tabs

4. MATHCAD TEMPLATE

PG&E uses Mathcad for developing and documenting the protection settings (line impedances, reach, pickup, etc.). A Mathcad template was created for the line and transformer applications. The breaker panel did not require a Mathcad template since standard settings were employed for breaker failure and the Excel resource guide was sufficient to document how the relay was configured.

5. DESCRIPTION OF OPERATION

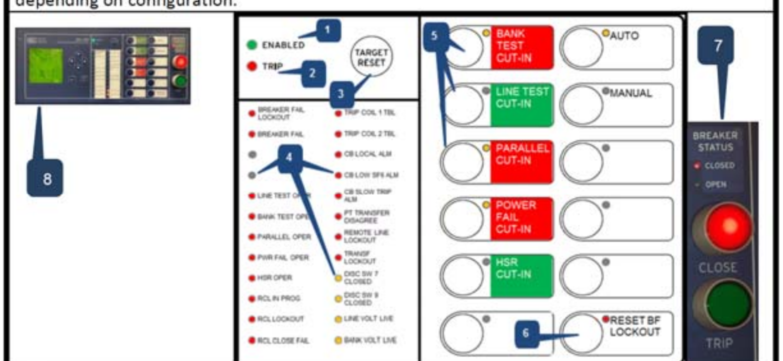
A Description of Operation (DOO) document was created for the SMP breaker, line, and transformer applications. The DOO was created and issued with the design standard. The DOO is primarily created as a reference for Operators but is also used as a reference for engineers and technicians to understand the basics of the SMP schemes.

6. SWITCHMAN JOB AID

A switchmen's job aid was developed that is printed and laminated and hung adjacent to the SMP relay panels. It is used a reference for switching when operating an SMP relay panel. This was very well received by switchmen and operators.

SMP Breaker Panel

Use this job aid when operating an SMP breaker panel. Pushbuttons and Target LEDs will vary, depending on configuration.

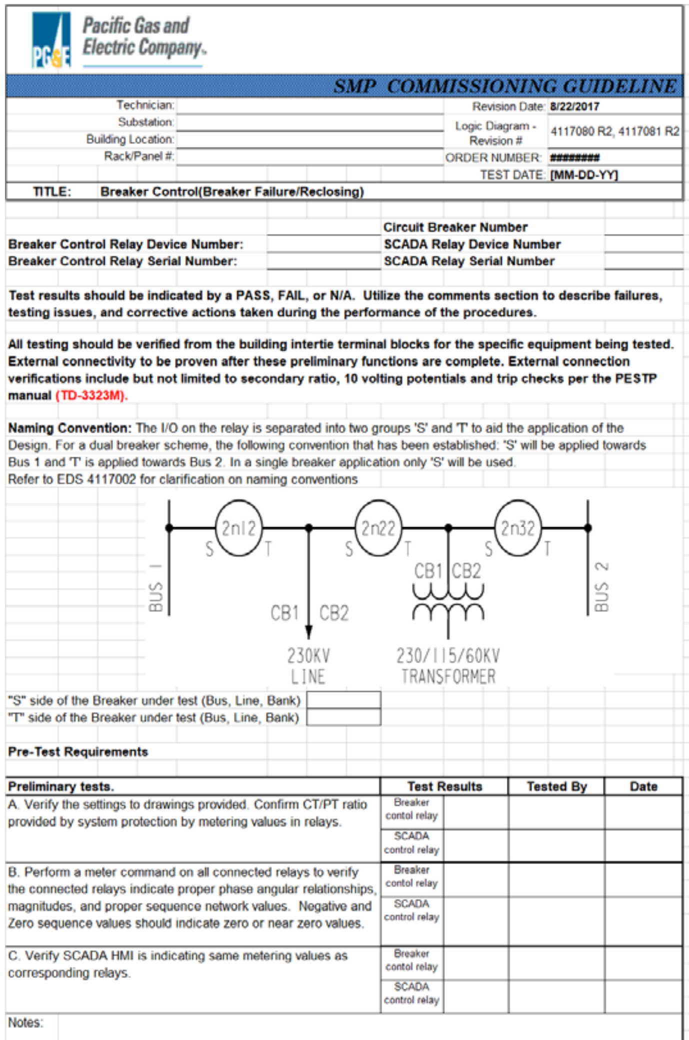


1	**ENABLED** - Green LED indicates the relay is powered.
2	**TRIP** - Red LED indicates the relay has sent a trip signal.
3	**TARGET RESET** - Resets red target LEDs, but it does not reset any timers.
4	**Target LED section** – • Lit Red LED indicates target • Lit Amber LED indicates Status, i.e. (what the label says is happening) • Dark LED indicates condition is not met, i.e. (what the label says is not happening)
5	**Pushbuttons Section** – Everything in this section is associated with auto and manual, except the RESET BF LOCKOUT button.
6	**RESET BF LOCKOUT** – After maintenance in the event of a breaker fail, the RESET BF LOCKOUT button must be pressed before closing this breaker or adjacent breakers.
7	**Breaker Trip and Close Pushbuttons** – Even if the relay fails, the breaker can still be opened using these buttons.
8	**Display Screen** – Rotating display shows metering, synchronizing and automatic timing information.

Figure 17 - SMP Switchman Job Aid

7. COMMISSIONING TEST DOCUMENT

An SMP relay Commissioning Guideline was created for each scheme type (line, transformer, breaker). This is a simple high level 2 to 3 page test document. The Site Acceptance Test procedures for the IPAC design was extremely detailed and about 30 pages long.



Pacific Gas and Electric Company.

SMP COMMISSIONING GUIDELINE

Technician:		Revision Date:	8/22/2017
Substation:		Logic Diagram - Revision #	4117080 R2, 4117081 R2
Building Location:			
Rack/Panel #:		ORDER NUMBER:	########
		TEST DATE:	[MM-DD-YY]

TITLE: Breaker Control(Breaker Failure/Reclosing)

		Circuit Breaker Number	
Breaker Control Relay Device Number:		**SCADA Relay Device Number**	
Breaker Control Relay Serial Number:		**SCADA Relay Serial Number**	

Test results should be indicated by a PASS, FAIL, or N/A. Utilize the comments section to describe failures, testing issues, and corrective actions taken during the performance of the procedures.

All testing should be verified from the building intertie terminal blocks for the specific equipment being tested. External connectivity to be proven after these preliminary functions are complete. External connection verifications include but not limited to secondary ratio, 10 volting potentials and trip checks per the PESTP manual (TD-3323M).

Naming Convention: The I/O on the relay is separated into two groups 'S' and 'T' to aid the application of the Design. For a dual breaker scheme, the following convention that has been established: 'S' will be applied towards Bus 1 and 'T' is applied towards Bus 2. In a single breaker application only 'S' will be used.
Refer to EDS 4117002 for clarification on naming conventions

"S" side of the Breaker under test (Bus, Line, Bank)	
"T" side of the Breaker under test (Bus, Line, Bank)	

Pre-Test Requirements

Preliminary tests.	**Test Results**		**Tested By**	**Date**
A. Verify the settings to drawings provided. Confirm CT/PT ratio provided by system protection by metering values in relays.	Breaker contol relay			
	SCADA control relay			
B. Perform a meter command on all connected relays to verify the connected relays indicate proper phase angular relationships, magnitudes, and proper sequence network values. Negative and Zero sequence values should indicate zero or near zero values.	Breaker contol relay			
	SCADA control relay			
C. Verify SCADA HMI is indicating same metering values as corresponding relays.	Breaker contol relay			
	SCADA control relay			
Notes:				

Figure 18 - Commissioning Test Document

Template Revision Tracking

It was desired to track revisions on the relay setting templates, logic diagrams and resource guide, and to tie them together. When a setting file is issued it is based on the latest version of the logic diagram at that time, but the standard logic diagram and setting template may later be updated. To document the logic revision that a setting file is based on, it was decided to imbed that information within the relay setting file. Each setting template contains the template version date, and associated logic diagram revision in the Notes settings.

An old setting file can be opened from the relay database or retrieved from the relay, and the logic revision and setting template revision that the settings were based on can be easily determined by going to the Notes settings. System Protection archives each revision of the logic diagrams so that they can later be referenced as needed.

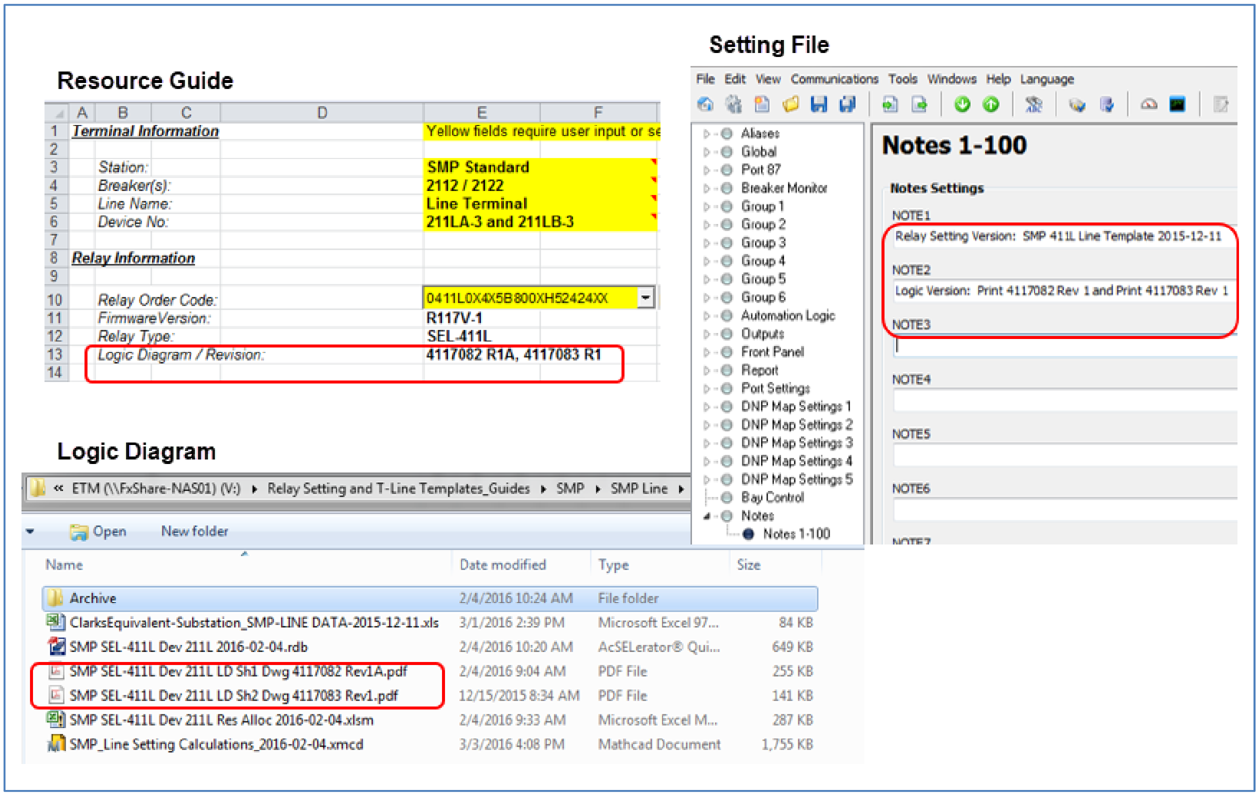


Figure 19 - Template and Logic Revision Tracking

VIII. Training

Due to painful lessons learned during the rollout of our IPAC standards, the authors devoted a great deal of time to providing training to different user groups after the SMP standard prints were released. This enabled a smooth rollout with less problems during initial projects and much happier users. Customized training was created for the following user groups:

1. Substation Design Engineers
2. Substation Project Engineers
3. SCADA Specialists
4. Switchmen
5. Transmission Operators and Dispatchers
6. Protection Engineers
7. Relay Technicians

Customized training slide decks were created for each group due to their different needs but many of the slides could be copied between groups. Some of the training was provided shortly after the standards were issued but some groups were provided "just in time" training spread over two years to ensure the training was received shortly before the first projects in their area using the new standard. The most detailed training was provided to the Protection Engineers and Relay Technicians. The Relay Technicians received one day of basic training from the relay manufacture on accessing and programming the relay as well as training and the significant differences between the previous logic format and their new enhanced logic format. They also received three days of just in time training that was structured with ½ day of lecture on each of the three design modules and ½ day of hands on training and testing in our test and training building. This proved very effective as they could see the design and test it immediately following the classroom training.

The Protection Engineers received three and a half days of initial training. This included ½ day of training from the relay manufacturer and 3 days of training from the authors. The switchmen training was created with our internal professional training staff who also scheduled and provided their training in the just in time format. They also produced the switchmen's job aid which is designed to be carried by the switchmen until they become comfortable with the new design.

IX. Conclusion

As a large corporation PG&E can justify the development costs of producing a protection design standard since it will be used on many terminals. The best practices detailed in this paper resulted in an extremely smooth rollout. The first two pilot projects using our SMP design were drop in modular control buildings that were designed and built by a different relay manufacturer from the relays used in our standard. Their questions during the project design helped us create a more robust set of standards and better design instructions. The authors answered minor questions over the phone during the on-site commissioning and testing of the pilot projects and never needed to provide on-site support. This was better much better than expected.

The steps to develop and implement a new protection design standard should address:

1. Management Approval and Stakeholder Input.
2. Rigorous relay selection and design criteria determination.
3. Test and refine the design before rolling out multiple projects.
4. Produce design standard prints that will apply to multiple bus configurations and protection schemes.
5. Create job aids and templates for engineers and users. This ensures consistency and reduces errors.
6. Train, Train and then Train some more.

Smaller companies can still use many of the steps and best practices to create a standard at a lower cost. Instead of using “go by” prints from the last project they should convert those prints to a design standard and institute a process to control changes and updates to those standards. Instead of using the last projects relay setting file and logic they can covert these to a standard template and standard logic with a process to control these and peer review changes. This will result in a higher level of consistency and quality of design. The authors are aware of companies that do not apply consistent design, settings or logic. This lack of consistency and a peer review process creates multiple opportunities for human performance errors by design, protection, technicians and operations

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(1) “Relay Scheme Design Using Microprocessor Relays” - Report to the System Protection Subcommittee of the Power System Relay Committee of the IEEE Power & Energy Society. Prepared by working group C16 June 2014

(2) “Commissioning Testing of Protection Systems” - Working Group report for IEEE PSRC, WG I-25, May 2017

(3) Multiple IEEE Standards and Working Group Reports.

The authors would like to thank the following individuals who were key to developing and rolling out the SMP standards. Jonathan Sykes, John McCall, Ben Nie, Monica Anderson, Frank Bringino, Brandon Gorham and Ezra Kidane.

BIOGRAPHIES

Scott Hayes received his BSEEE from California State University, Sacramento in 1985. He started his career with Pacific Gas and Electric Company in 1984 as an intern. Since then he has held multiple positions in System Protection including supervisor, as well as Distribution Engineer, Operations Engineer, Supervising Electrical Technician, Supervising Engineer in Power Generation and is currently a Principal Protection Engineer focusing on standards, procedures and quality. Scott has previously co-authored papers for the Western Protective Relay Conference, Georgia Tech, TechCon Asia Pacific, CEATI Protection and Control Conference and Transmission and Distribution World Magazine. Topics include Thermal Overload Relays for Intertie Lines, Data Mining Relay Event Files to Improve Protection Quality, Effects of CCVT Ferroresonance on protective relays and PG&E’s Wires Down Program. Scott is a registered Professional Engineer in the state of California and has served as Chairman of the Sacramento Section of the IEEE Power Engineering Society. He is currently the chairman of the CEATI Protection and Control Program and is a member of the NATF protection core team. He has also served on a NERC Standard Drafting Team.

Aaron Feathers is a Principal Engineer in System Protection Engineering at Pacific Gas and Electric Company, where he has been employed since 1992. He has 26 years of experience in the application of protective relaying and control systems on transmission systems. Aaron's current job responsibilities include design standards, wide area RAS support, NERC PRC compliance, and relay asset management support. Aaron has previously co-authored multiple papers for the Western Protective Relay Conference and Georgia Tech, and presented at Distributech. Topics include Relay Integration/Modular Control Buildings, Relay Polarizing/Coordination, and multiple papers on Relay Asset Management, one of which was selected for the Walter Elmore Best Paper award at the 2013 Georgia Tech Relay Conference. He has a BSEE degree from California State Polytechnic University, San Luis Obispo and is a registered Professional Engineer in the State of California. He is also a member of IEEE and is on the Western Protective Relay Conference planning committee and participated on the NERC Protection System Maintenance Standard Drafting Team that developed NERC Standard PRC-005-2 through PRC-005-6.