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Configuration and Setting Management for Protection and Control Systems

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Technical Update, December 2011

EPRI Project Manager

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ABSTRACT

The Electric Power Research Institute (EPRI) roadmap reports, *Roadmap for the Next Generation Protective Devices* (1017774) and *Current State Assessment: Next Generation Relays* (1017773) forecast that as protection equipment and systems continuously evolve in the more feature-rich and sophisticated direction, management of the configuration and setting is becoming more critical. In the 2011 EPRI Protection and Control (P&C) survey, configuration and setting management for protection and control systems remains one of the most pressing challenges for member utilities.

Based on the feedback from the 2011 P&C survey and task force meetings, the following are the causes of the challenge:

- Growing functionality, flexibility, and complexity of modern digital relays
- Organizational structure and existing administrative and management processes
- Distinct interests and needs of using P&C data in different groups
- Reliability and compliance requirements from regulatory standards

To handle the growing complexity of today's P&C asset management and to improve power system reliability, effective processes and tools are required to develop, exchange, maintain, and control mission-critical P&C data in a consistent and sustainable way. A well-established configuration and setting management system will become an essential part of the entire P&C asset in the near future.

This report provides an update on the project progress in 2011. More specifically, the report describes a case study and an analysis of the configuration management issues at the perspective of protective relays, elaborates the 2011 task force meeting minutes, and lists the directions for the next step R&D activities.

Keywords

Configuration
Intelligent electronic device
Management
Protection and control
Relay
Setting

ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
CIP	critical infrastructure protection
GOOSE	generic object oriented substation event (IEC 61850)
GUI	graphical user interface
HMI	human-machine interface
I/O	inputs/outputs
IEC 61850	IEC standard for communication networks and systems in substations
IEC	International Electrotechnical Commission
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronics Engineers
IPS	Intelligent Process Solutions
IT	information technology
LED	light-emitting diode
NERC	North American Electric Reliability Council
P&C	protection and control
pu	per unit
PMU	phasor measurement unit
rms	root mean square
RTDS	real-time digital simulator
SCADA	supervisory control and data acquisition
SCD	system configuration description (an IEC 61850 configuration file)
SCL	substation configuration language
XML	extensible markup language

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INTRODUCTION

Background

In 2009, EPRI carried out an investigation of utility industry issues with current generations of protective relaying and of industry needs for the future. The EPRI report *Current State Assessment: Next Generation Relays* (PID:1017773) addresses the current state for the industry, and the EPRI report *Roadmap for the Next Generation Protective Devices* (PID: 1017774) presents a roadmap based on the current state. Both reports convey concerns gathered from meetings of industry experts.

One of the major concerns expressed by many experts in the current situation investigation is with the complexity of setting today's microprocessor relays and managing the settings and firmware versions of a large protection fleet. Setting or configuration errors pose a serious risk for protection misoperation and therefore threaten the overall reliability of power systems.

The roadmap report forecasts that as protection equipment and systems continuously evolve in the more feature-rich and sophisticated direction, management of the configuration and setting is becoming more critical in future. Without a proper management and process in place, operation personnel can easily make mistakes by accidentally changing relay parameters in service.

In the EPRI report *Current State Assessment: Next Generation Relays* (1017773), the section "Development and Standardization of User Tools" was one of the requirements that the development of tools for management and control of protection system settings mentioned. The report addressed the critical issue of microprocessor relays and Ethernet communications devices having hundreds of settings, any one of which could cause misoperation. The normal maintenance technique for equipment failure is to replace an entire unit, so a management system must support rapid setting of the replacement device, as well as closed loop verification of setting correctness. New protection system maintenance standards require that in condition-monitored relays not subject to routine time-based testing, the settings are verified as correct by some means other than testing—this must be a tightly managed and documented settings control system. In addition, the settings storage and management tool needs to be tied to protection setting tools, notably coordination study programs, as well as to unified system modeling proposed in the next section.

2011 P&C Survey Results

At the beginning of year 2011, EPRI performed a utility industry survey with the goal to obtain a good understanding of the research needs from members, and relocate the limited research fund to the highest priority tasks. Nice research directions were collected from the P&C task force meetings and listed in the Table 1-1 for the survey.

EPRI received the survey responses from 14 utilities. The aggregated survey result shown in Table 1-2 clearly indicated that "*Task A - Setting and Configuration Management of P&C Systems*" remained as one of the top priority research tasks for EPRI.

Table 1-1
2011 P&C Survey – Research Topics Under Considerations by P&C Task Force

2011 P&C Survey

Nine (9) Tasks were under consideration:

Task A	**Setting and Configuration Management for P&C Systems**
Task B	**"Aurora Threat" - Protection Functionality Assessment, Gap Identification and Risk Mitigation**
Task C	**Understand the emerging IEC 61850 standard and its impact on P&C: Training and Hands-on Workshop**
Task D	**Understand the emerging IEC 61850 standard and its impact on P&C: IEC 61850 Tutorial and Use Cases**
Task E	**Towards a Full-Condition-Monitoring-Based Low-Maintenance P&C System**
Task G	**Synchrophasor Relaying**
Task H	**Advanced Sensor Technologies for P&C Applications**
Task I	**Special Protection Systems**
Task J	**Understand Functionalities and Features of Modern Digital Relays**

Table 1-2
Survey Result – High Priority Topics Identified From the Responses of 14 Utilities

2011 Survey Results

Task	PS37H Member											Average (Member)	Non-Member			Average (All)
A	1	2	1.5	4	3	1	2	6	5	1	2	2.41	9	1	3	2.82
B	4	1	5.5	9	1	2	1	9	2	4	8	3.50	4	6	5	3.82
C	8	9	1	1	5	3	5	4	4	1	4	3.73	7	8	X	4.00
D	7	8	1.5	2	5	3	4	3	3	2	3	3.50	8	9	X	3.96
E	5	3	4	3	2	5	3	1	1	5	1	2.91	1	2	2	2.64
G	6	6	4	6	6	6	6	5	6	7	4	5.27	2	3	4	4.79
H	9	7	2.5	7	7	4	7	7	7	7	4	5.86	3	5	6	5.61
I	3	5	5.5	8	4	7	8	2	8	7	5	5.23	6	4	7	5.32
J	2	4	7	5	3	8	9	8	9	7	2	5.64	5	7	X	5.29

Note: smaller number indicates a higher priority. The yellow cell indicate the “top 3” for each member.

Task A	Setting and Configuration Management for P&C Systems
Task B	"Aurora Threat" - Protection Functionality Assessment, Gap Identification and Risk Mitigation
Task C	Understand the emerging IEC 61850 standard and its impact on P&C: Training and Hands-on Workshop
Task D	Understand the emerging IEC 61850 standard and its impact on P&C: IEC 61850 Tutorial and Use Cases
Task E	Towards a Full-Condition-Monitoring-Based Low-Maintenance P&C System

Although the EPRI report *Emerging Protective Relay Issues: Settings and Configuration Management for Protection and Control Systems* (PID: 1020025) was published in 2010, the survey responses showed that more research work need to be done to support utilities in overcoming the issue. Also the project deliverables such as practical guidelines and best practice would be more helpful and more beneficial to utilities than a high-level outline report.

With the feedbacks received from P&C task force members, the project re-started in a fresh way and with the focus on developing guidelines and practical solutions that utilities can apply in the field.

This technical update report summarizes the 2011 research findings and proposes the next-step work plans to achieve the goals.

2
UNDERSTAND THE CHALLENGES

Before looking for any solution, it is important to fully understand what kind of issues and challenges utilities are facing today with managing the settings and configurations associated with protection systems. There are many contributing factors and aspects of the difficulty. A good research approach is to start with a simple but illustrative case study by analyzing the setting and configuration from a selection of protective relays.

A Case Study: Settings of an Overcurrent Function (ANSI 51)

With the protection and control technologies evolved from electro-mechanical relay to microprocessor based digital relay, and now towards intelligent electronic device (IEDs), the concept and the scope of configuration and setting for protective relays have been changed significantly. To understand the difference, let's compare the settings of a standardized and commonly-used protection function - ANSI 51 time-overcurrent function for an electromechanical relay and a variety of state-of-the-art digital relays.

Case 1: A type CO electro-mechanical relay (ABB 41-101H)

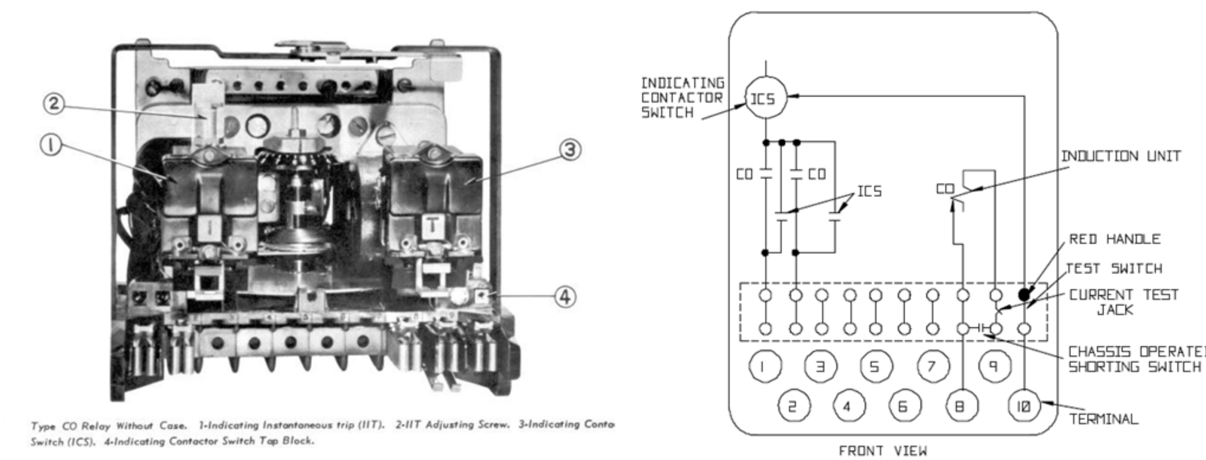

Figure 2-1
A Type CO Electro-mechanical Relay (ABB 41-101H)

Figure 2-1 shows a sample of electro-mechanical relay with front view and wiring diagram. The settings for the time overcurrent relay are listed in Table 2-1. Because of the simplicity of the functionality, there are only three "settable" parameters which represent the three essential settings for ANSI 51 function. In the wiring diagram shown in Figure 2-1, the relay's input and output (I/O) have been pre-wired and cannot be re-configured. In addition, any change of the setting will require physical adjustment of the components in the device.

Table 2-1
Time Overcurrent Settings in Electro-mechanical Relay (ABB 41-101H)

Setting Name	Setting Value	Note
Curve	ANSI Inverse	Fixed by Relay Type
Tap	1	Pick up I = 5 Amp
Time Dial	2	Td = 5 second

Case 2: SEL Multi-function Digital Relay (SEL421)

Figure 2-2 shows the time overcurrent settings and the configuration tool for a SEL421 digital relay. To set the time-overcurrent function in the SEL421 relay, the relevant settings are listed in Table 2-2.

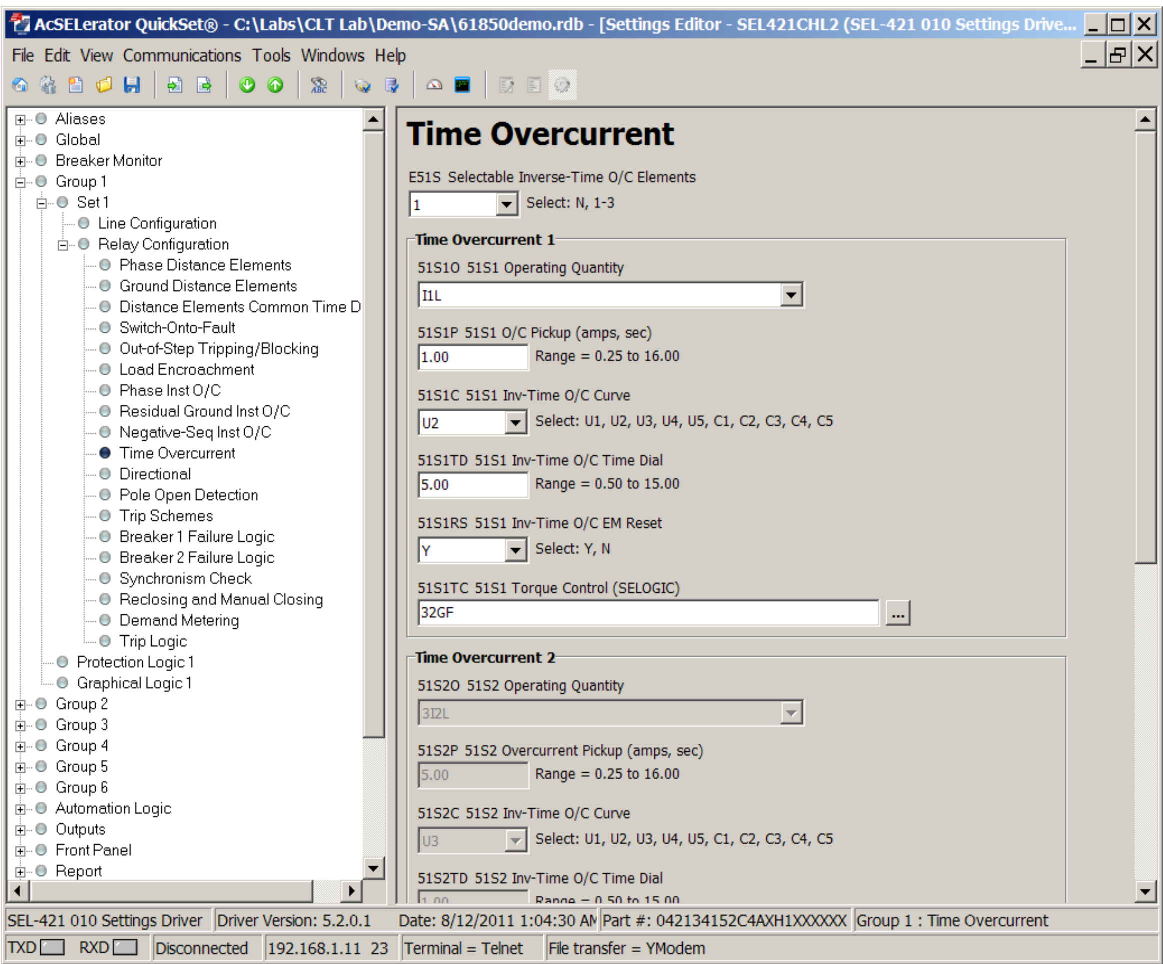

Figure 2-2
Time-Overcurrent Settings and Configuration Tool for a SEL421 relay

Table 2-2
Time Overcurrent Settings in a SEL 421 Relay

Setting Name	Value	Explanation
51S1O 51S1 Operating Quantity	I1L	Choose current quantities. "I1L" stands for "Line positive sequence current"
51S1P 51S1 O/C Pickup	**1.00**	**Pick up current = 1.00 * Inom = 5 Amp. Note that the setting is a per unit value based on nominal current (5 Amp in this case).**
51S1C 51S1 Inv-Time O/C Curve	**U2**	**Choose the ANSI/IEEE inverse curve. Note that the symbol "U1 –U5, and C1-C5" represent different predefined curves.**
51S1TD 51S1 Inv-Time O/C Time Dial	**5.00**	**Time Dial = 5 second**
51S1RS 51S1Inv-Time O/C EM Reset	Y	Choose "Y(es)" to mimic the characteristic of electro-mechanical relay; or choose "N(o)" to reset without time delay.
51S1TC 51S1Torque Control	32GF	Set/add a "Torque Control" to supervise the protection function.

Case 3: Siemens Multi-function Digital Relay (7SJ64)

Figure 2-3 shows the configuration tool for a Siemens 7SJ64 digital relay. To set the time-overcurrent function in the 7SJ64 relay, the relevant settings are listed in Table 2-3.

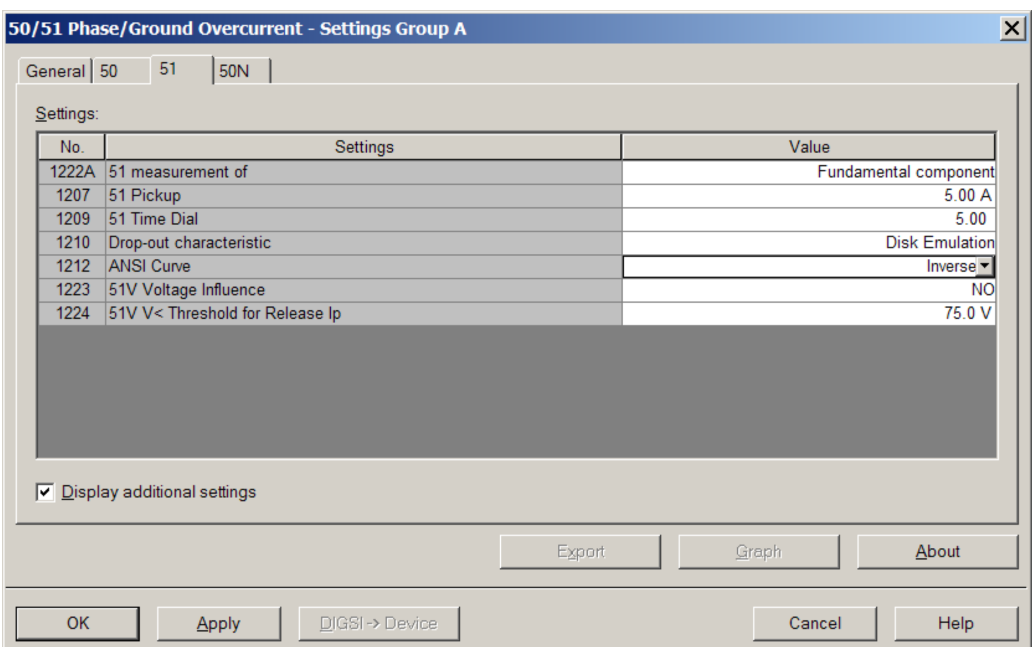

Figure 2-3
7SJ64 Configuration Tool and User Interface

Table 2-3
Time Overcurrent Settings in a Siemens 7SJ64 Relay

Setting Name	Value	Explanation
51 measurement of	Fundamental Component	Choose between the “magnitude of fundamental frequency component” and RMS value.
51 Pickup	**5.00A**	**Pick up I = 5 Amp**
51 Time Dial	**5.00**	**Time Dial = 5 second**
Drop-out characteristic	Disk Emulation	Choose “Disk Emulation” to mimic the characteristic of electro-mechanical relay; or choose “instantaneous” to reset without time delay.
ANSI Curve	**Inverse**	**Select a curve to use. Note: there are 7 ANSI curve options available and more IEC curve options.**
51V Voltage Influence	No	This is an additional feature to provide a “voltage restraint” time overcurrent. The pickup setting can be dynamically adjusted based on voltage level and pre-defined “Pickup-Voltage” curve.
51V< Threshold for Release Ip	75.0V	51V pickup setting

Case 4: GE Multi-function Digital Relay (T60)

Figure 2-4 shows the configuration tool for GE T60 digital relay. To set the time-overcurrent protection function in the GE T60 relay, the relevant settings are listed in Table 2-4.

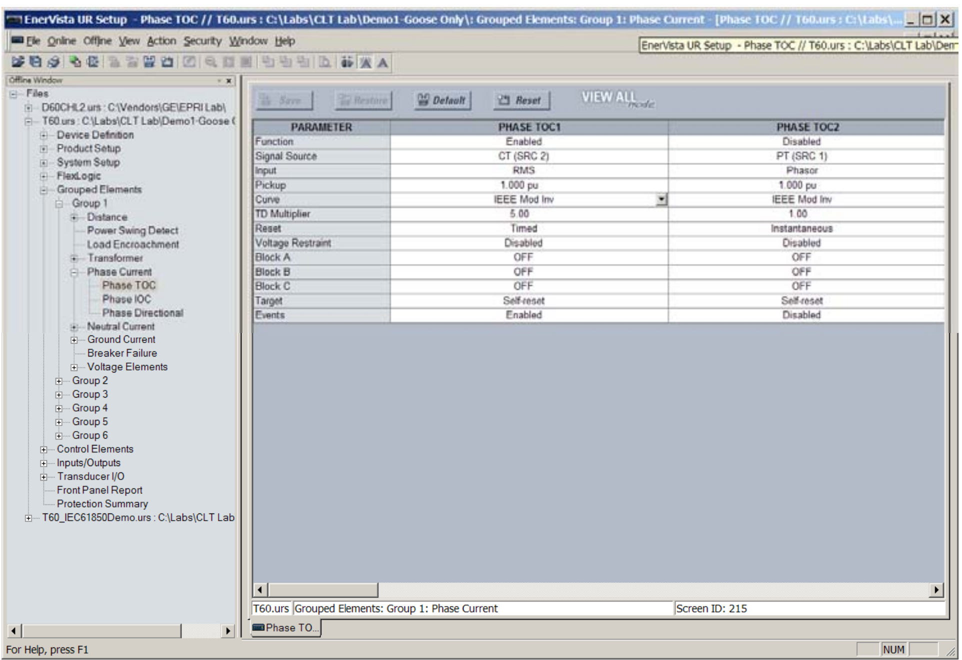

Figure 2-4
Configuration Tool and User Interface for a GE T60 relay

Table 2-4
Time Overcurrent Settings in a GE T60 Relay

Setting Name	Value	Explanation
Function	Enabled	Enable phase time overcurrent function
Signal Source	CT (SRC2)	Choose the source of current measurements
Input	RMS	Choose between “phasor - magnitude of fundamental frequency component” and RMS value
Pickup	**1.00pu**	**Pick up I = 5 Amp. Note that this relay uses per unit (pu) instead of Amp.**
Curve	**IEEE Inverse**	**Select a curve to use. Note: there are 15 curve options available, but ANSI/IEEE inverse wasn’t available at the time.**
TD Multiplier	**5.00**	**Time Dial = 5 second. Note that the setting of “TD Multiplier” is the same as “Time Dial” used in other vendors’ relays.**
Reset	Timed	Choose “Timed” to mimic the characteristic of electro-mechanical relay; or choose “instantaneous” to reset without time delay.
Voltage Restraint	Disabled	This is an additional feature to provide a “voltage restraint” time overcurrent. The pickup setting can be dynamically adjusted based on voltage level and pre-defined “Pickup-Voltage” curve.
Block A/B/C	OFF	Additional inputs for customized protection logics
Target	Self-reset	Choose “self-reset”, “latched” or “disabled” for target
Events	Enabled	Add the time overcurrent status in event report

Case 5: Areva Multi-function Digital Relay (P145)

Figure 2-5 shows the configuration tool for an Areva P145 digital relay. To set the time overcurrent protection function in the P145 relay, the relevant settings are listed in Table 2-5.

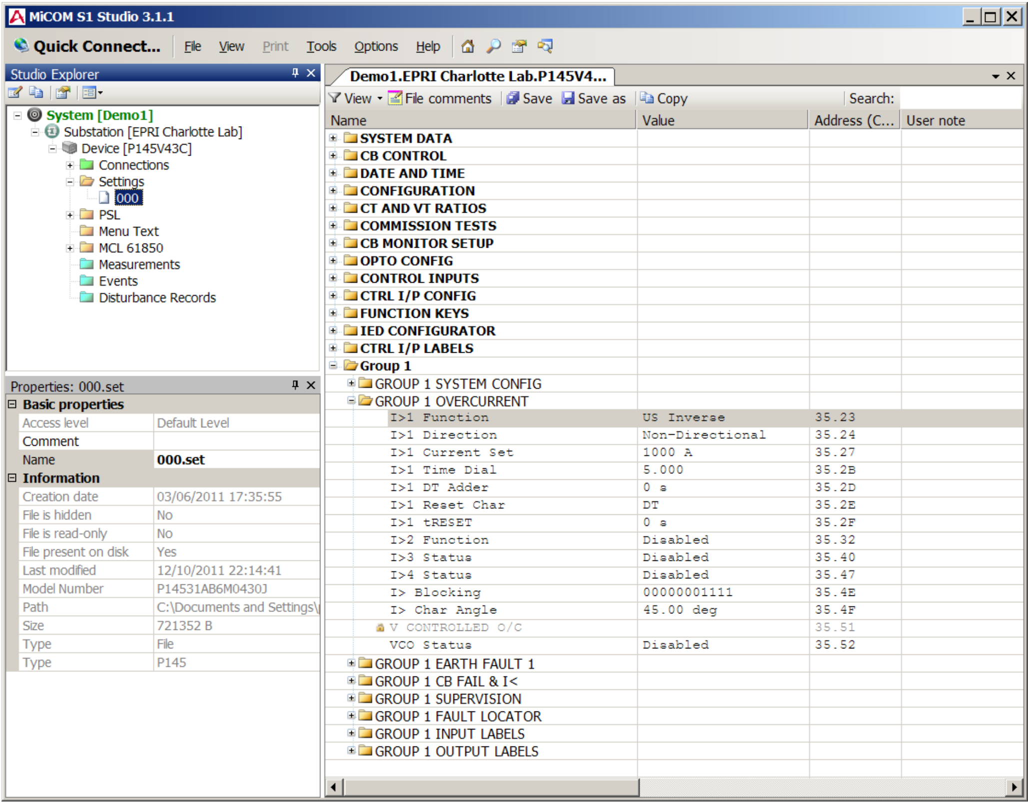

Figure 2-5
Areva P145 Configuration Tool and User Interface

Table 2-5
Time Overcurrent Settings in Areva P145 Relay

Setting Name	Value	Explanation
I>1 Function	**US Inverse**	**Select a curve to use. Note: there are 12 curve options available.**
I>1 Direction	Non-Directional	Choose to use directional element (forward and reverse) or non-directional
I>1 Current Set	**1000 Amp**	**Because the CT ratio setting is 1000/5, 5Amp secondary setting has been automatically converted to primary value (1000 Amp in this case).**
I>1 Time Dial	**5.00**	**Time Dial = 5 second**
I>1 TD Adder	0	Set additional fixed time delay to the selected curve
I>1 tRESET	0	Set a reset time delay
I>2 Function	Disabled	Enable the second stage of overcurrent element
I>3 Status	Disabled	Status of the third stage of overcurrent element
I>4 Status	Disabled	Status of the fourth stage of overcurrent element

Table 2-5 (continued)
Time Overcurrent Settings in Areva P145 Relay

Setting Name	Value	Explanation
I> Blocking	000000001111	Bit 0 = VTS Blocks I>1, Bit 1 = VTS Blocks I>2, Bit 2 = VTS Blocks I>3, Bit 3 = VTS Blocks I>4, Bit 4 = A/R Blocks I>3, Bit 5 = A/R Blocks I>4. Bits 6 & 7 are not used.
I> Char Angle	45.00 degree	Setting for the relay characteristic angle used for the directional decision.
VCO Status	Disabled	Allows selection of whether voltage control should be applied to each of the first or second stage overcurrent elements.

The findings of the case study

From the case study, we have the following observations:

- **Digital relays significantly increase the number of settable parameters.** Generally, the amount of settings offered by a relay is directly proportional to the number of built-in protection functions. Typically, an electro-mechanical relay is a single-function device and offers a very limited number of settings. In contrast, the number of functions that a microprocessor-based digital relay can provide could be hundreds, and it is only limited by the relay's data processing capability.

  In the case study, as we can see, for the time-overcurrent function, besides the three essential settings (curve, pickup, time-dial), most of the digital relays provide the following additional settings:

  – Selection of measurement and operating quantities. With the modern digital filtering technology, digital relays now can measure any of following quantities: fundamental-frequency component (positive sequence current), root-mean-square (RMS) value, negative sequence current, or more. Thus, the time-overcurrent function can be applied to any of these quantities to meet the needs of various applications. In contrast, the electromechanical relay can only use the RMS value.

  – Selection of reset methods. Digital relays can provide two options: instantaneous reset or disk-reset, while electromechanical relays can provide only the disk-reset.

  Each digital relay also provides a number of vendor-specific settings based on different design philosophy or marketing preference. These vendor-specific settings provide more flexibility and features for protection applications, however, they also increase the complexity of configuration management as they are not standardized and may cause relay misoperation if not properly configured or disabled.

- **Not all settings offered by digital relays are necessarily used.** In the case study, besides the three essential settings (curve, pickup, time dial), all the digital relays provide a number of extra settings to expand their protection capabilities.

  For instance, the "51V - Voltage Restraint Time Overcurrent" is an optional function provided by most digital relays in the case study. For the scenarios that system voltage drops significantly during a fault, the 51V function can improve the sensitivity of over-current protection by dynamically adjust the pickup settings in proportion to the system voltage level. It will be very helpful for certain applications, however, in many cases, 51V function may not be used and therefore should be properly turned off.

  It is quite common nowadays that a digital relay provides more functions than users actually need. Having extra functions in relay can provide certain degree of future-proof and cost saving for utilities, however, on the other side, it increases the complexity and work load for configuration and setting. To understand all of the built-in functions and properly disable these unused functions could be a big effort during relay commissioning or field maintenance. Relay misoperations have been reported due to the unused functions which weren't properly turned off.

  Protection setting and relay setting are not the same things. The typical protection settings created by a system coordination or planning engineer consists of only the basic and essential protection parameters. For instance, the time overcurrent function has three essential settings: curve, pickup and time dial. However, to implement the protection function in a digital relay, a relay or P&C engineer will have to convert the basic protection settings into proper relay settings. Normally, they are not the same. Understand the meaning of each relay setting is imperative in order to correctly implement the protection functions. A digital relay has evolved into a very sophisticated and versatile industry computer which was specifically designed for the P&C applications. In order to properly implement the selected protection functions, it is necessary for utility staff to gain a good understanding of the underlying principles and the actual meaning of each relay setting. In some cases, tests may be necessary to detect any misinterpretation and verify the functional settings in relaying products.

  For instance, in the case study, some digital relays don't use *Ampere* as the unit for the pickup setting, instead, they use a per unit basis. For a per unit setting, if the setting of nominal current is 5 Amp, the protection setting (pickup = 5 Amp) has to be converted into relay setting (pickup =1 pu) so the relay can proper operate.
- **Relay settings are not standardized and highly vendor-dependant.** From the case study, it is very obvious that even though the protection functions have been standardized by standard organizations, such as IEEE/ANSI/IEC, it is up to the relay manufacturers to decide how to implement the functions and name the relay elements in their products.

Such design freedom certainly spurs the creativity and competition among relay vendors. On the other hand, however, it greatly increases the difficulty for utilities to manage the P&C settings from multi-vendor products. For instance, in the case study, the following names have been used by different relay vendors even though they all mean the same "curve" setting:

– 51S1C 51S1 Inv-Time O/C Curve = "U2";
– ANSI curve = "Inverse";
– curve = "IEEE Inverse";
– I>1 Function = "US Inverse".

And the following setting names were used in various digital relays for the same pickup setting: "51S1P 51S1 O/C Pickup", "51 Pickup", "Pickup", "I>1 Current Set".

Therefore, it is impossible to exchange protection settings between different vendor products or configuration tools, except through a tedious and error-prone manual process. To get familiar with vendor's products and protection function designs, training and education of P&C staff become a high cost for most utilities. To reduce the costs and simplify the management process, as a matter of fact, some utilities choose to use only single vendor' products for their entire P&C asset, even though such single-vendor practice will pose the risk of vendor "lock-in" in the future.

- **Relay settings are software and firmware dependant.** Since the information technology has been introduced to the digital relays, there is a version control issue with the configuration software (in computer) and the associated firmware (in digital relay). Similar to the service patches from software manufacturers, nowadays utilities are continuously receiving upgrades of relay software and firmware from time to time. In a newer version, vendors may add new functions or fixed some errors from the previous release. Because the protection functions or settings are highly dependent upon the firmware version, such version updates shall be included in the process of configuration and setting management.
- **New skill set for P&C workforce.** With the fast and ever evolution of protection and control technologies, the skill set for utility workforce has been significantly expanded. The following diagram shows the trend of the desired skill sets for P&C workforce in the near future.

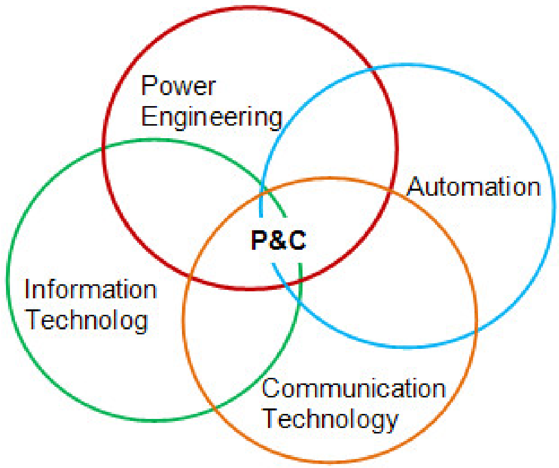

Figure 2-6
Trend of desired skill sets for P&C workforce

Traditionally, P&C skill set is mainly in the power engineering domain and has little overlapping with other areas. With the introduction of microprocessor-based digital relays since 1980s, information technology, such as computer and software, became an essential part of P&C skill set. Nowadays, with the power infrastructure in North America moving towards a “smarter grid”, communication and automation technologies are playing a crucial role and will impact on the P&C system development as well. For instance, the IEC 61850 standard and Ethernet technology is one good example showing the merging trend for skill sets of power engineering, information technology, communication, and automation. Alternatively, a utility P&C division in future could also consist of a group of subject-matter experts from each individual knowledge domain and work together as a team.

The skill set changes will also lead to the organizational changes. The following function divisions may get directly or indirectly involved in the P&C business:

– Protection system engineering
– Relay/IED engineering, testing, maintenance
– Substation communications and Information Technology
– SCADA and RTU engineering, testing, maintenance
– Substation automation engineering, testing, maintenance
– Disturbance analysis
– Compliance and auditing
– Cyber security

In summary, the case study reveals the industry status and issues with the management of settings and configurations. However, the case study didn't include the aspects of protection system modeling, coordination studies, or creation of protection settings normally done by system study or planning groups. In order to understand the complete issues and challenges in managing protection data asset, as the next stage of the project, the research work will be expanded to include the entire life cycle management of relay data asset.

Understand the Configurations for Protective Relays

The functionality and flexibility of today's digital relays continue growing. Figure 2-7 shows the state-of-the-art digital relays and configuration software tools in EPRI relay lab. Digital relays are no longer limited to provide only the protection functions. There are many more other settings and configurations which may be directly or indirectly related to the protection functions. This chapter looks into the difficulty of managing these protection-relevant setting and configurations.

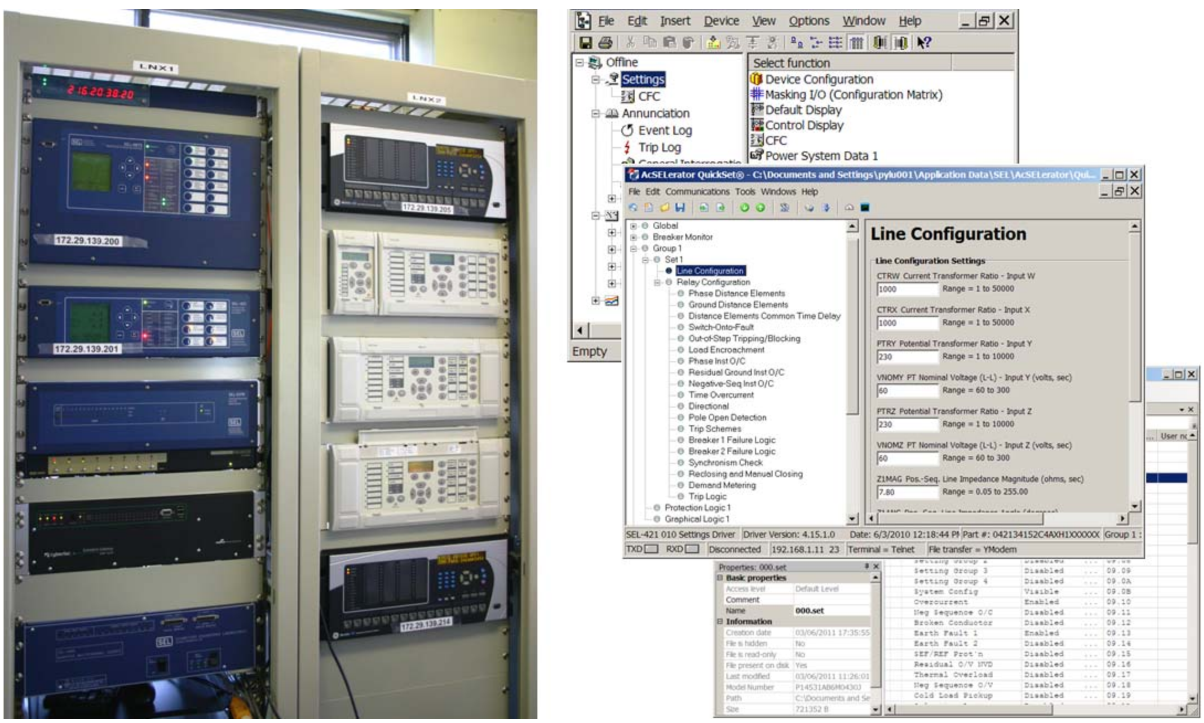

Figure 2-7
Digital Relays and Configuration Software Tools in EPRI Relay Lab

The functions of a digital relay can be classified generally into three broad categories: protection, control, SCADA/RTU. Table 2-8 provides a list of relay functions falling into each category.

Table 2-6
Expanded Scopes for Setting and Configuration in Modern Digital Relays

Protection Function Settings	Control Function Settings	SCADA/RTU Function Settings
Protection elements (ANSI 50, 51, 21, 87, etc)	Local Control	RTU/SCADA Communication
Protection Logics	Automation Logics	Measurement and Metering
Inputs (CT/PT connections, Binary inputs, etc)	Control Pushbuttons	Phasor Measurement Unit (PMU) – for wide area protection and control applications
Outputs contacts (Trip/Close contacts, etc)	Relay HMI/GUI	Remote Control
Communication configurations (Pilot schemes, GOOSE messaging, etc)	LED Indicators	
Sequence of Event (SOE) and Fault Recording		
Time Synchronization		
Phasor Measurement Unit (PMU) – for wide area protection and control applications		

Protection logic configuration

Besides the "static" protection settings, most digital relays nowadays have the embedded configurable logic processing capability, which provides almost unlimited flexibility for customized P&C applications.

On the other hand, the unlimited flexibility and convenience create a challenge on the configuration management. To understand the difficulty, let's firstly take a look at how the protection logics are being configured in various digital relays.

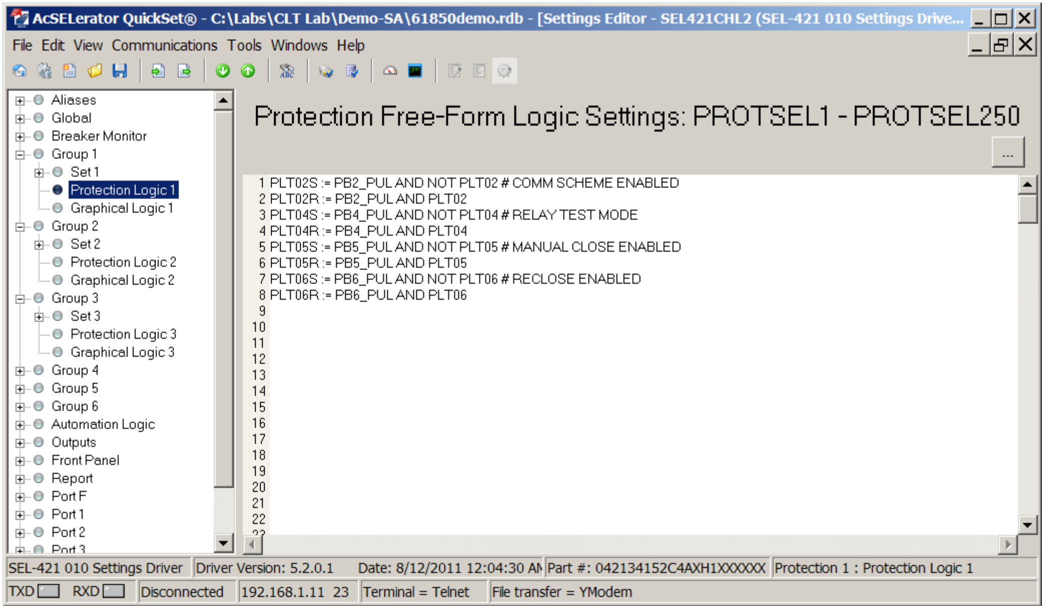

Figure 2-8
Protection logic configuration described by a proprietary text-based language

Figure 2-8 shows a logic configuration language and the user interface. The text-based logic configuration is similar to protection settings, except it is a free format and fully customizable. The signals that can be processed in the logics are limited to the available relay words which are pre-defined by the manufacturers. Documenting the logics and changes can be performed using any text editor, which is an advantage of using text-based configuration environment.

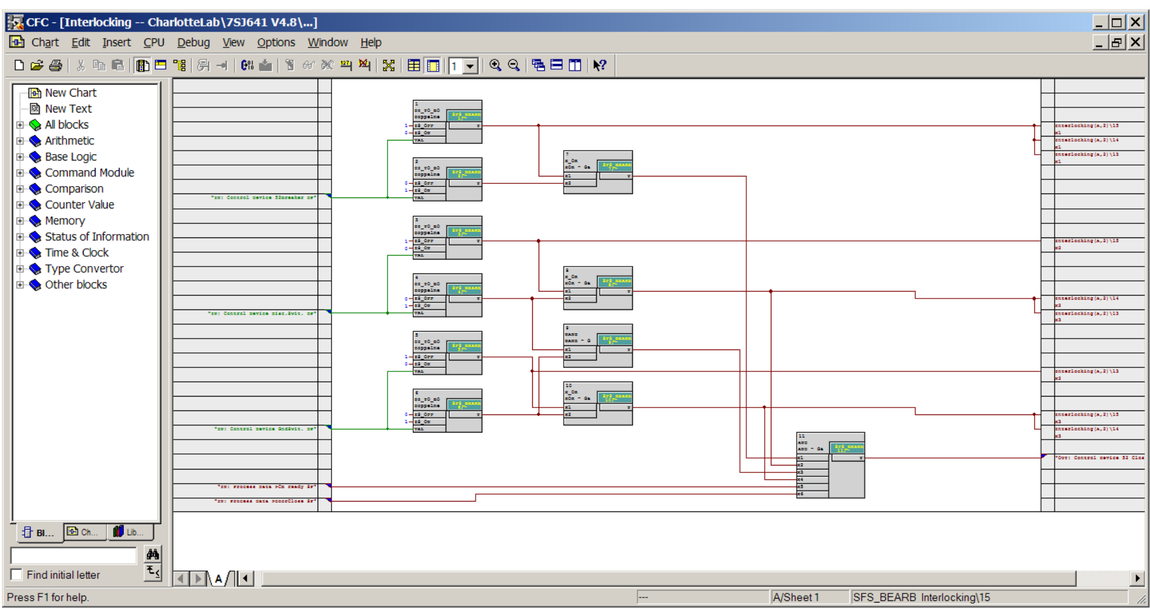

Figure 2-9
Protection logic configuration described by a proprietary graphic language

Figure 2-9 shows a logic configuration language and tool based on a user-friendly graphic interface. The graph-based logic configuration is completely different from traditional protection settings. The concept and technology are similar to the programmable logic controllers which are widely used in the automation and control industry. The signals that can be processed in the logics are not limited by the manufacturers, users can freely create their own signals as well as use the existing signals from various sources, such as input contacts or communication channels. However, due to the unlimited freedom, documenting the logic design and keeping track of the changes are the challenges in such highly flexible configuration environment.

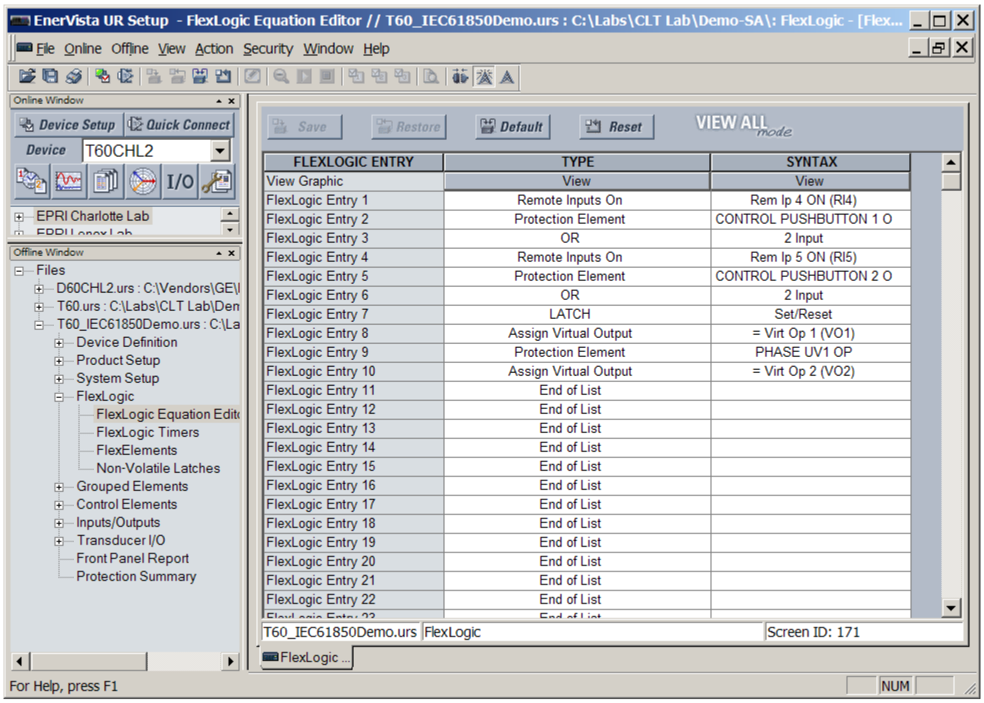

Figure 2-10
Protection logic configuration described by a proprietary language

Figure 2-10 shows a logic configuration language and tool based on a "drop-list" interface. The process is similar to the text-based approach, except all the signals have been pre-defined and listed in the "drop table" for each setting.

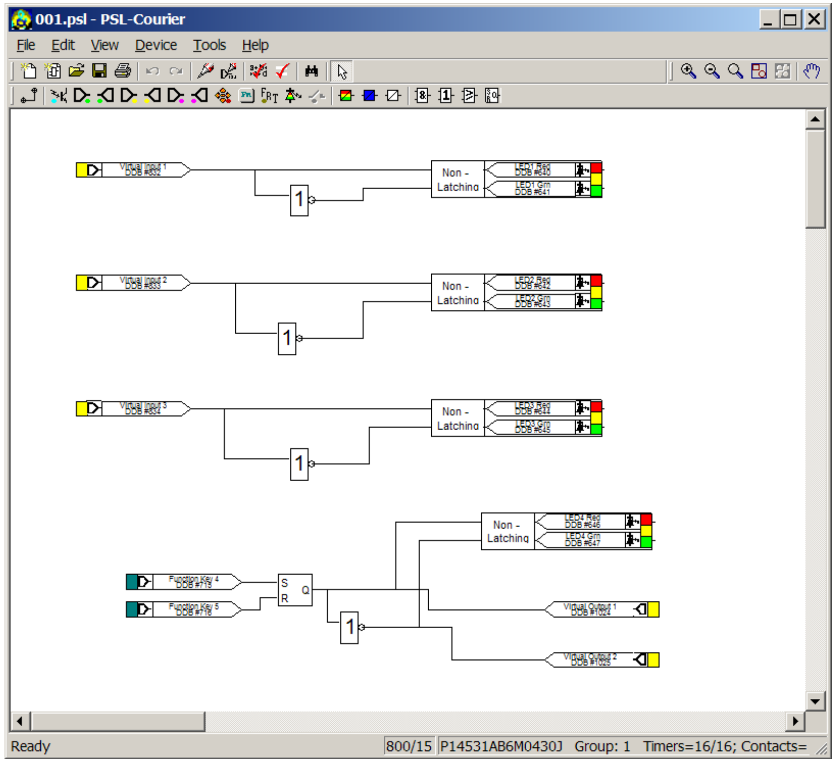

Figure 2-11
Protection logic configuration described by a proprietary graphic language

Figure 2-11 shows a logic configuration language and tool based on a graphic user interface. The configuration process is similar to the case in Figure 2-9, but the entire configuration environment, including all the symbols, language, signal names, conventions, are different and vendor-specific.

In summary, Figure 2-8, 2-9, 2-10 and 2-11 show the different tools and languages used for configuring protection logics. It is obvious to draw the conclusion that the configuration methods for protection logics are highly vendor-dependant and non-standardized. Although some vendors adopted the IEC 61131, which is an IEC standard for programmable logic controllers (PLCs), the configuration tools and procedures remain non-standardized and device-oriented.

Because the protection logics are part of the entire protection settings, they should be tightly managed and well maintained as conventional protection settings (like pickup, time dial, etc). Unlike the conventional protection settings, logic configurations are normally represented in a graphic environment, which makes it hard to manually check and verify the correctness of the configurations especially for complicated protection schemes.

All protection logics should be carefully designed and fully tested before put into service, however, it is very easy to make any changes in the logic configuration either intentionally or unattendedly during relay maintenance or setting update.

Documentation of the protection logic is a very important and sometimes becomes an omitted step. A well documented logic configuration will make it much easier for maintenance and troubleshooting.

Given the unlimited flexibility of logic configuration and a large fleet of P&C asset, it may be a good practice for utilities to standardize the protection functions including the protection logics, which could dramatically reduce the management cost or human errors.

Inputs and outputs configuration

Besides the protection element settings, the correct operation of a protection function requires the correctly configured input and output signals/contacts.

With today's digital relaying technology, the input and output signals (I/O) fall into two general categories:

- Hardwired signals or contacts, which include current transformers (CTs), voltage transformers (VTs), binary inputs, output contacts, transducers or special sensing devices, etc;
- Communication signals, which may include dedicated protection channel signals (such as line differential signals), SCADA signals for protection purposes, peer-to-peer communication signals (such as proprietary Mirrored Bits®, or standard-based GOOSE messaging).

In digital relays, the hardwired input signals or output contacts can be easily configured and mapped to relay words (internal signals).

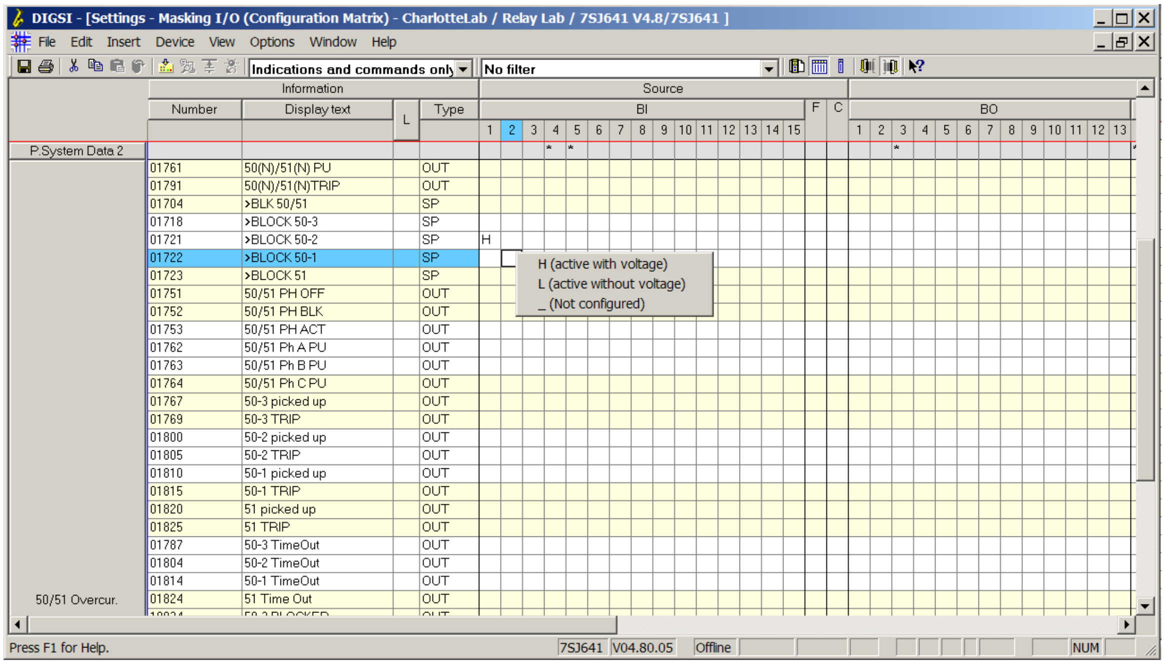

Figure 2-12
Binary inputs can be freely configured to any relay words

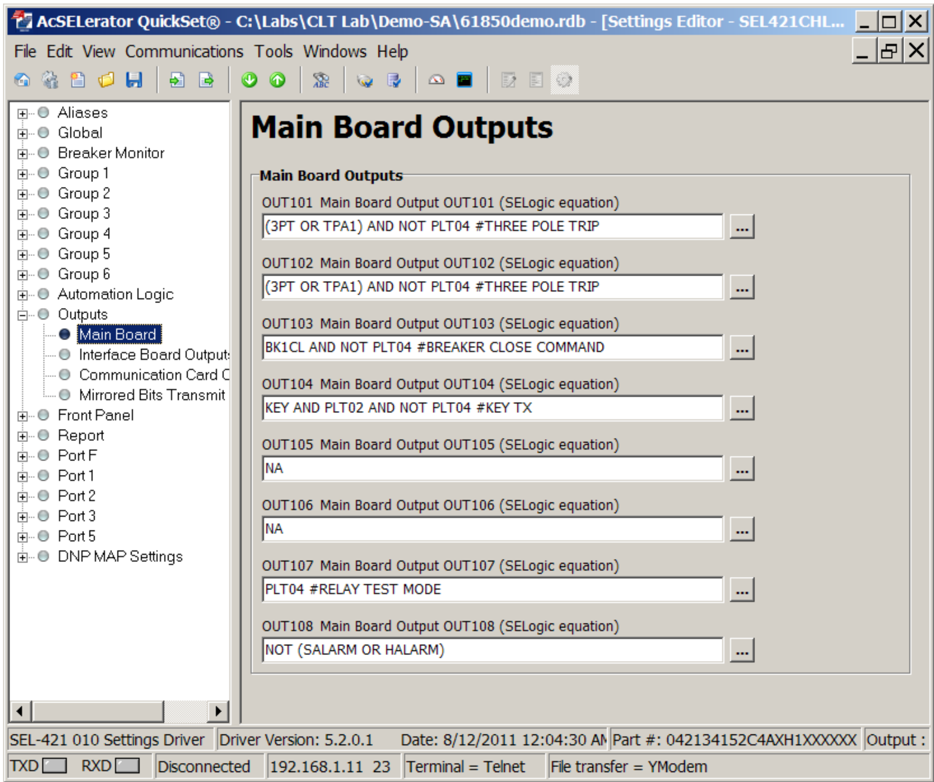

Figure 2-13
The closing logic of each binary output contact can be freely configured

Figure 2-12 shows a user interface for configuring binary inputs (BIs) and binary outputs (BOs). In this case, every input or output can be freely configured to any relay word (internal signal). For instance, in the Figure 2-12, binary input number 2 is being configured to the signal which can block the stage-1 overcurrent element (ANSI 50). Moreover, the blocking signal can be configured as "active" either with or without voltage across the input contact.

Figure 2-13 shows a user interface for configuring binary outputs. In the design, binary output contacts can be freely configured to close on the "assert" of any relay word or logic formula. It provides the basically unlimited flexibility for customizing protection and control applications.

On the other hand, from configuration management perspective, a miss-configured input or output by a software tool is equivalent to a miss-wired terminal in a marshalling panel in the electro-mechanical era, except now it becomes much easier to click mouse to make a "wiring change" than do it physically like before.

The relay I/O through communication channels can be configured in a similar way. The difference is that instead of using physical input or output contacts, communication signals use virtual I/Os. A digital relay usually provides a much larger number of configurable virtual I/Os, as they are not limited by physical size of a relay.

Because I/Os are the essential and critical part of the entire protection scheme and they are very easy to be configured or changed in digital relays, they should be tightly managed and properly tested. As we can see from the Figure 2-12 and Figure 2-13, I/O configurations or settings are vendor-dependant. The good knowledge on specific devices is necessary for correct configuring the I/O signals. Normally, I/O signals are documented on DC schematic drawings or spread sheets, then there is a manual process for relay or P&C engineers to program and map the I/O signals into the devices.

Event and fault recording configuration

With the increasing emphasis of post-event analysis from grid reliability regulators, even though the event and fault recording functions are not required for the correct operation of protection functions, they become a critical tool for verification and documentation of relay operations. Therefore, the configuration of event and fault recording functions should be properly managed as well.

The typical settings for event and fault recording include:

- Trigger conditions. What condition(s) should trigger a relay to record the event?
- Analog channels and digital elements to be included in the report and/or oscillograph records. A digital relay may have thousands of available status signals, but not all of them are needed for every event analysis.
- Duration of the event recording. With the limited memory in a digital relay, events can be recorded only in a certain time window.

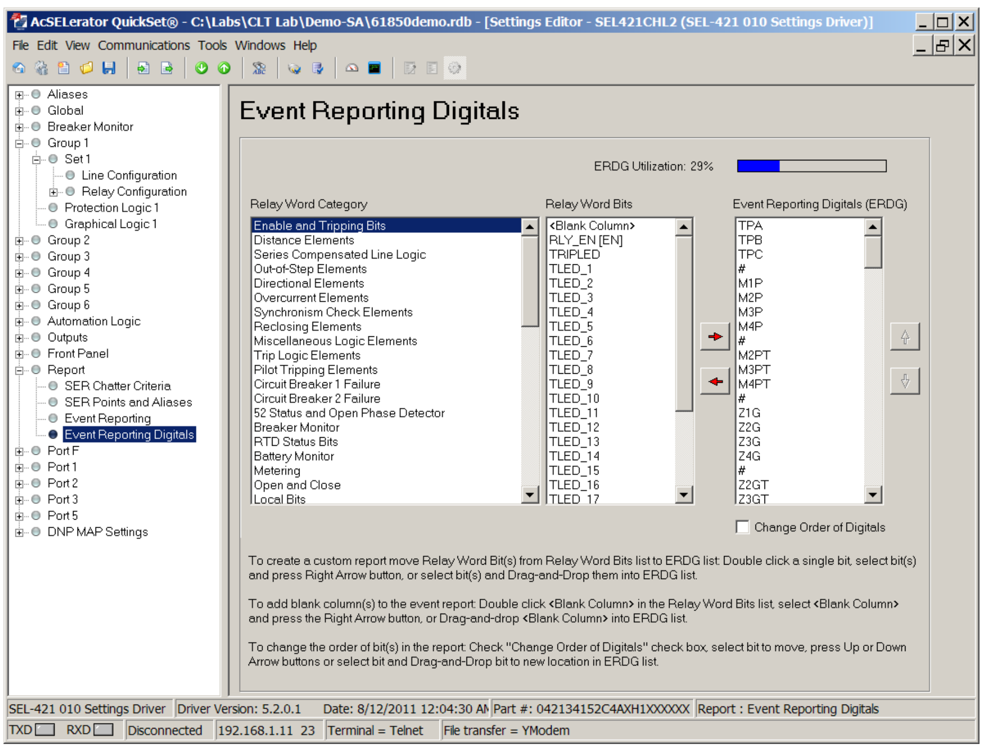

Figure 2-14
Configuration of relay words (internal signals) to be included in an event report

Figure 2-14 shows an example of configuring an event report by including relevant relay signals and analog channels.

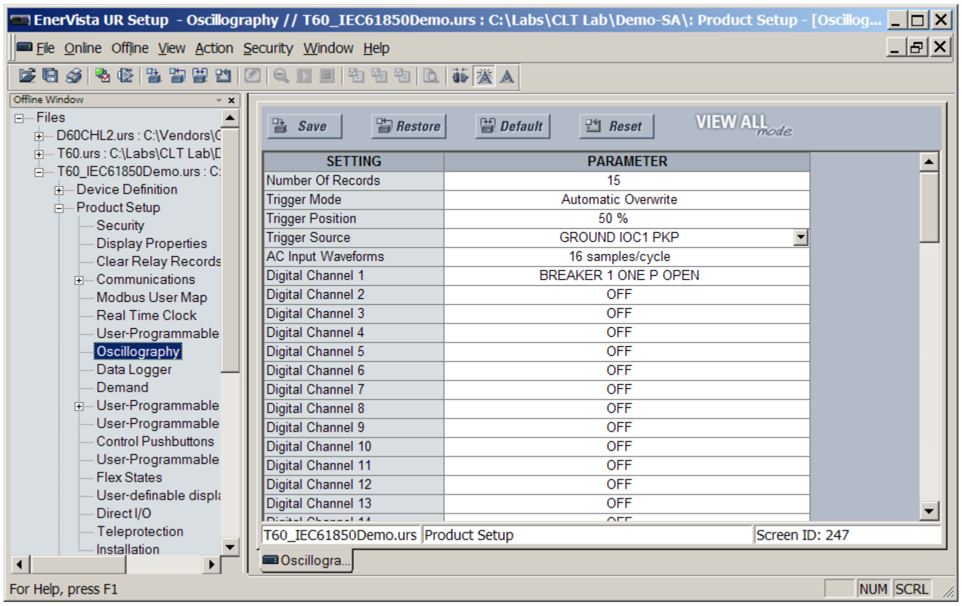

Figure 2-15
Configuration of relay analog and digital signals in oscillograph records

Figure 2-15 shows another example of configuring an oscillograph report by specifying the triggering conditions, waveform properties, and the signals to be recorded.

Time synchronization configuration

Traditionally, most protective relays don't need the precise time clocks or time synchronization signals. However, the situation is changing due to the following reasons:

- The synchrophasor functions have been integrated in many protective relays. To measure a synchrophasor, the precision of the relay time is critical. If the synchrophasor technology is used for wide area protection and control, the precise time synchronization becomes an essential part of the entire protection scheme.
- The precise time synchronization is required for post event analysis, especially by using the fault records from multiple protective relays.
- Digital relays are gradually replacing RTUs. The precision time stamps are required for most RTU measurements.

There are a number of technologies utilities can use for time synchronization: IRIG-B, Network Time Protocol (NTP) or Simplified NTP (SNTP), IEEE 1588. For all of these methods, the proper configuration in protective relays, as well as auxiliary device such as GPS clock, is generally required.

A summary of the protection-related configurations

For the proper operation of a protection scheme or function, besides the essential protection element settings, there are many other protection-related settings and configurations in digital relays that utilities need to take into account. These configurations or settings are typically vendor-dependant or even device-dependant, which requires specific knowledge of the relaying devices.

Because any error in the protection-related configurations may lead to the failure of protection functions, utilities should treat them as part of the protection settings and placed them in a tightly managed system or practice.

Impact of the IEC 61850 standard

The IEC 61850 standard introduced many new concepts and procedures in the configuration and setting of protective relays. Utilities in the process of migrating to the IEC 61850 standard will soon face the new technology environment which requires new process and tools for configuration and setting management.

In IEC 61850 standard, the so-called "substation configuration language (SCL)" has been extensively used for device configuration purposes.

Following is a brief summary of the relay files standardized by the standard:

- ICD - IED (intelligent electronic device) capability description
- CID - configured IED description
- SSD - system specification description
- SCD - substation configuration description
- IID – instantiated IED description

Figure 2-16 is a simplified diagram showing the relationship between these standardized configuration files. Figure 2-17 is a simplified diagram showing the engineering process by using these standardized configuration files. The impact of using SCL for configuration and setting of IEC 61850-based protection and control systems will be covered in 2012 technical update.

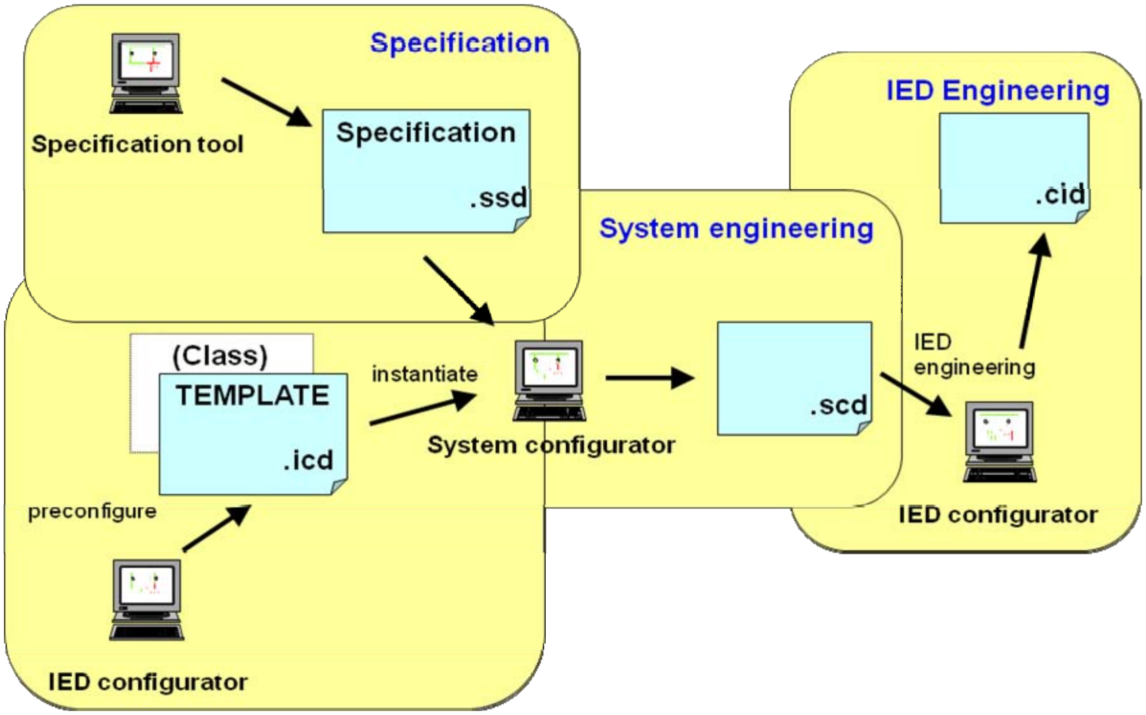

Figure 2-16
System integration process by using the standardized SCL files

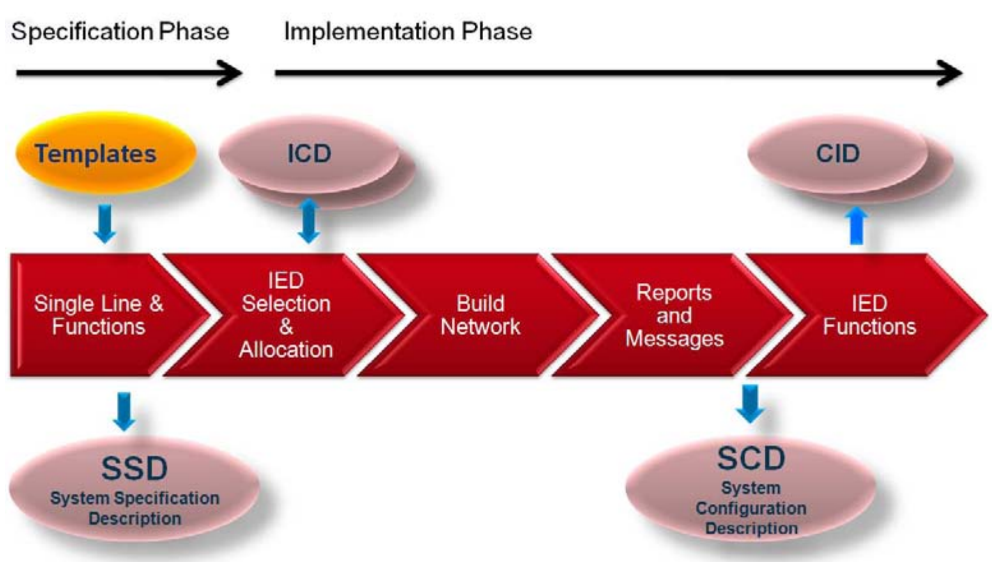

Figure 2-17
Engineering process by using the standardized SCL files.

Impact of the Reliability Standards and Compliance Requirement

Since 2007, utilities have faced a step increase in the requirements and costs of maintaining the high reliability of their protection systems, as they work to comply with North American reliability standards for the Bulk Electric System (BES) written and audited by NERC and regional reliability organizations (RROs), and designated as mandatory and enforceable by FERC. A well-constructed P&C maintenance program should include a properly-designed management system for configurations and settings, as well as a good tracking and documenting system for the testing/maintenance records.

More discussion and studies of the impact of reliability standards and compliance requirement on the configuration and setting management for protection systems will be performed in 2012.

A summary of the challenges of configuration and setting management

Utilities are facing growing complexity in the management of configuration and settings for protection and control systems. This chapter performed a case study and applied an analytic method to reveal the key issues and technical hurdles that caused the difficulty.

In summary, the following factors are contributing to the difficulty of managing the configuration and settings for protection systems:

- Significantly increased functionalities in digital relays;
- Hundreds of settable parameters as a result of the functionality increase in digital relays;
- Almost unlimited configuration flexibility and customization capability in digital relays;
- The great diversity of relay products and vendor implementation;
- Non-standardized and highly-vender-dependant protection data format and configuration tools;
- Major impact of the adoption of the IEC 61850 standard for protection systems;
- Synchrophasor and other non-traditional protection functions being integrated in digital relays;
- Profound impact of the increased requirements and compliance needs for the reliability of protection systems in North America.

Obviously, the list above is not a complete or conclusive summary of the causes of the difficulty. The research and study in this chapter were mainly at the perspective of digital relaying equipment, therefore the system level management of configuration and settings may need to be addressed in future development of the project. For instance, except through a error-prone manual process, how to easily and reliably transfer the protection settings from system coordination study tools, such as CAPE® or ASPEN™, to various vendor products?

A good understanding of the causes of the difficulty is the first step in the process of find a sound solution. The continued research and studies will be performed in 2012 to further identify and categorize all the possible causes, so the solutions proposed in next steps can be directed to hit the right targets.

3
TASK FORCE MEETING MINUTES

EPRI Protection and Control (P&C) task force met in New York City on August 1-2. In the meetings, the task force members reviewed the project progress and collectively provided much-needed guidance on the further project development. This chapter provides a summary of the task force meeting minutes.

- The management of setting and configuration for P&C systems is considered as a challenge by the task force:
  - Proper management of the critical P&C data asset requires necessary administrative functions or processes. Technical tools can help implement or automate the management process, but tools cannot replace a well-designed work flow or quality control process. Before any technical solution to be implemented, it is more important to well understand what kind of process and functional requirement will be needed for each utility organization. The actual needs or situation from each utility may not be the same in most cases.
  - Different function groups or divisions from a utility organization may get involved in the management process. During the data transition from one group to another, issues like miscommunications or human errors may occur. In some utility, because of the historical reasons like company merging, offices at different locations may have very different but well-established practices.
  - The users of protection data may have very different interests. For instance, a system planning engineer is mainly interested in the settings which have the impact on the coordination of various protective zones or the system stability, however, he/she may not be interested in how the protection functions will actually be implemented in a specific relay model. In contrast, a relay or P&C engineer pays great attention on the implementation details for specific protective equipment, but it is out of his/her responsibility to check the protection settings for the reasons of system stability or protection coordination.
  - Every utility seems different in the current way of managing protection settings and configuration data, as it really depends on so many practical factors, such as the size of the company, the structure of the organization and work force, relay products being installed, etc.
  - Protection setting data from different tools are typically not exchangeable. System protection engineers may use the tools different from what relay engineers use, and different vendor tools cannot exchange protection setting data. The protection setting data generated by system protection engineers using the tools, such as CAPE® or ASPEN™, have to be properly “translated” into vendor-specific “relay language” and programmed into the relays. Usually, it is a tedious and error-prone manual “translation” process. This issue has driven the industry to look into a possible solution called “common data format”.

- The task force think the project should focus on the management of protection related settings and configuration.
- Task force members shared the experience of implementing “Quality Control (QC)” and “Quality Assurance (QA)” in the setting and configuration management. QC is a process to audit setting and identify potential issues; QA is a process to implement the necessary procedures to ensure the quality of settings. Peer review of protection setting as quality control procedure has been implemented in some member utilities. However, human errors can still occurs particularly when utility in-house resources are very limited in today’s work environment.
- Today, almost every utility handled the protection data management in a very different way. In some cases, even within the same utility organization, different offices create and maintain their own management processes.
- To successfully manage configuration and setting, certain administrative process is normally required. Since no two utilities have the same organizational structure and management environment, it is hard to recommend a generic process that fits all utilities.
- A number of task force members suggested that it would be beneficial if the project can collect and share the existing practices from different utilities, and have a workshop to have a brainstorm on “what do we think the best practice and what will it take to implement it?”
- The upcoming new regulation requirements (PRC-005-2) tend to drive utilities to implement or enhance the quality control process for protection systems.
- The task force members had an extensive discussion on the “common data format” for protection functions. Below are the highlights.
  - Exchanging relay databases (ASPEN/CAPE) between different utilities is a common practice. But relay settings are generally not exchangeable between two relays from different vendors or even the same vendor.
  - There were two different concepts: protection data exchange and relay data exchange.
  - Relay date exchange: task force members commented that there were so many “tiny adjustments” or proprietary settings in the relay configuration files, therefore it seems impractical to create a common data or file format.
  - Protection data format: task force members commented that it might be “arguably” possible to have a “common data format” for protection functions. IEEE power system relaying committee (PSRC) has a working group (H5) addressing this need.
  - The concept of the “common data format” for protection functions was compared with the SCL files defined in the IEC 61850 standard. By using the standardized SCL format, different vendor tools can export/import the SCL files and understand the setting and configuration coded by the XML (eXtensible Markup Language) format.
  - The task force members suggested that it would be beneficial to keep informed on the progress of the IEEE “common data format” for protection functions.

- One task force member suggested that the data management experience from other industries (telecom, IT, etc) could be helpful for achieve the goals of this project. For instance, telecom industry has a large number of routers/switches, how do they handle settings, configurations, or firmware upgrades?
- Most task force members agreed that understand the available tools and solutions for configuration and setting management could be useful.

4 NEXT STEP WORK PLAN

Collect the use cases and document the best practices

One of the research directions suggested by the task force members is to collect and document existing practices and experiences of configuration and setting management from member utilities. The use cases should include the details of work flow, procedures of quality control and quality assurance, data management methodologies, and useful tools.

With the availability of use cases, a workshop will be hosted to "deep dive" into these use cases, analyze and compare the different processes, generate a technical report summarizing the findings which the P&C task force would consider as the "best practices".

Perform function assessment of the management tools

Utilities have employed various tools in support of the management process. Some tools are the commercially available products, some were developed by the utility in-house staff. All of these tools aim to simplify and automate the process of protection data asset management. In 2012, the EPRI Protection and Control lab, in collaboration with a number of vendors and solution providers in the protection asset management areas, will leverage the lab equipment and resources to perform a function assessment of a variety of management tools. The goal is to research and document the state of the art of configuration and setting management methodologies, understand the benefits of using the tools, identify the limits and technical gaps, and create "hands-on" case studies using the multi-vendor relays in the lab. Figure 4-1 shows protective relaying facilities in the EPRI P&C lab. The configuration and setting management tools available in the lab come from CAPE, Enoserv, Intelligent Process Solutions, and relay vendors.

Figure 4-1
EPRI Protection and Control Lab

Update on the development of the common data format for protection functions

Ideally, if the settings of protection functions could be described by a set of commonly agreed and well-understood data format, it will dramatically simplify the exchange and management of protection settings from different vendor tools and relay products. The effort of creating the "common data format" for IEDs has been taken mainly by the working groups of IEEE power system relaying committee since 2008.

As suggested by most of the task force members at the New York task force meeting, the project will keep track of the progress of developing the common data format for protection functions. The 2012 project report will provide a status update in this development direction.

5
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