POWER SYSTEM RELAYING COMMITTEE

Quality Assurance for Protection and Control Design

Prepared by Working Group I12

Working Group Assignment

To develop a special report outlining industry practices of Quality Assurance for protection and control design drawing packages.

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1. Purpose For Report

Throughout the electric utility industry, the drive to maximize quality assurance practices has gained increased prominence. These practices mitigate common errors frequently encountered in engineering design packages, specific to Protection and Control (P&C) design.

This report will illustrate industry practices to be applied in a Quality Assurance Program for protection and control design drawing packages; from conception to final "as-built." It is the reader's responsibility to incorporate these practices into their organization's Quality Assurance Program.

2. Introduction

A P&C design package for a substation or power plant includes many types of interconnected drawings that together demonstrate how to construct the systems and how they will ultimately function to control the power system. These drawings may include: one line diagrams; functional diagrams; panel arrangements; protection zone diagrams; bills of material; control house layouts; AC schematics; DC schematics; elementaries; wiring diagrams; equipment diagrams; cable schedules; circuit schedules and indices. Additional drawings are based upon the customers or end user's specifications and requirements. The accuracy of the comprehensive set of drawings is critical to ensuring proper construction, testing, and operation of the power system. Errors in the drawings can cause construction schedule delays, construction errors, increased costs, testing issues, safety precautions and ultimately a P&C system that does not align with the design criteria for which it was intended to comply.

The need for a Quality Assurance Program for P&C design packages stems from the complexity of the print package as a whole. A large transmission substation can have numerous prints detailing hundreds of thousands of connections. Even a low error rate can cause systems not to function as intended. An accurate set of P&C drawings must be put through a quality control check to ensure the drawings consistently and accurately reference one another so the intended functionality will be accomplished. Wiring diagrams are derived from elementary and schematics, and when there is an error on any one of them, the error carries forth.

The aim of a Quality Assurance program is to provide confidence that the project will meet its quality requirements. This involves the prevention of defects and deficiencies which could bring project deliverables out of compliance with their acceptance criteria. An effective Quality Assurance Program should, at minimum, address the following issues:

a. Clarity in the project's Scope Definition
b. Roles and responsibilities
c. Effective communications with the team members and stakeholders
d. Effective work practices and design processes implemented by qualified personnel

e. Document control
f. Peer review
g. Point-to-point checks
h. As-built documentation

This report will outline the best quality assurance practices used by leading industry organizations to ensure the accuracy of protection and control print packages.

3. Definitions

Quality Assurance – The planned and systematic activities implemented in a quality system so quality requirements for a product or service will be fulfilled.

Quality Control – The techniques and activities used for observation, evaluation and corrective action used to fulfill requirements for quality.

As-Built Drawings – A collection of prints from a construction project that indicate a change, mark-up or left as is on each print.

Record Drawings – Existing prints of record for an entire substation which shows the latest printed status of the substations configuration. Once the As-Built drawings are finalized, they become drawings of record. Drawings of record have no mark ups or changes noted on them, and they have been typically signed by a reviewer.

Checklist - A written minimum comprehensive collection of items (list) such as a series of names of activities, titles of documents, or titles of engineering drawings, used to compensate for deficiencies of human memory or attention. A checklist is often used to achieve human accountability and it is a needed part of the process to ensure a good quality project.

Point-to-Point Check – A point to point check verifies the wiring diagram accuracy against the associated schematics.

Peer Review - In protection and control design, a peer review is the evaluation of a set of design prints by another qualified individual with a focus on functional accuracy and correct application of devices based on the specific scope of work of the projects.

4. Communications, Accountability & Respect

Protection and control projects and operations embrace several different groups within the power industry. Whether planners, project managers, asset management personnel, procurement, design staff or field engineers, it is essential to establish a solid communications highway based on clearly defined roles and responsibilities.

Initial communication ground rules are developed in the early stages of a project based on the roles and responsibilities assigned to the project team members and stakeholders for assigned tasks. The project manager should strive for team development continually from the moment the team is formed. Team development is centered on activities to bring the individuals together to function as a team, and to better understand and address their strengths and weaknesses. In doing so, the project participants will gain respect for and from each of the team members. Team development also includes appropriate training of the project staff to ensure they have the necessary tools to successfully fulfill their role in the project. This aspect demonstrates each team member's value, thus supporting a healthy morale within the project team.

A successful quality assurance process can be achieved when the overall purpose for the process is always kept in mind during planning and implementation. To hold peers accountable and to treat everyone with respect is to provide a tool for improvement in the many dimensions of the projects. Lastly, to provide quality to clients at any level means to actively care about the safety, processes, procedures and financial responsibilities that are involved in the developing of protection and control packages.

5. Industry Resources

a. NERC

NERC publishes advisories ("Lessons Learned") as industry resources which provide technical and applicable information to assist in maintaining the reliability of the bulk power system. A robust Quality Assurance Program for protection and control design drawing packages can aid in an entity's NERC compliance. For example a Quality Assurance Program can specifically address issues affecting NERC Standard PRC-004.2.1a – *Analysis and Mitigation of Transmission and Generation Protection System Misoperations* by reducing the number of misoperations caused by design errors. As shown in Figure 1, the number one cause of NERC misoperations is "incorrect settings/logic/design errors." Utilizing proven Quality Assurance processes, focused on the area of protection settings and protective device coordination, can help reduce the occurrence of these misoperations.

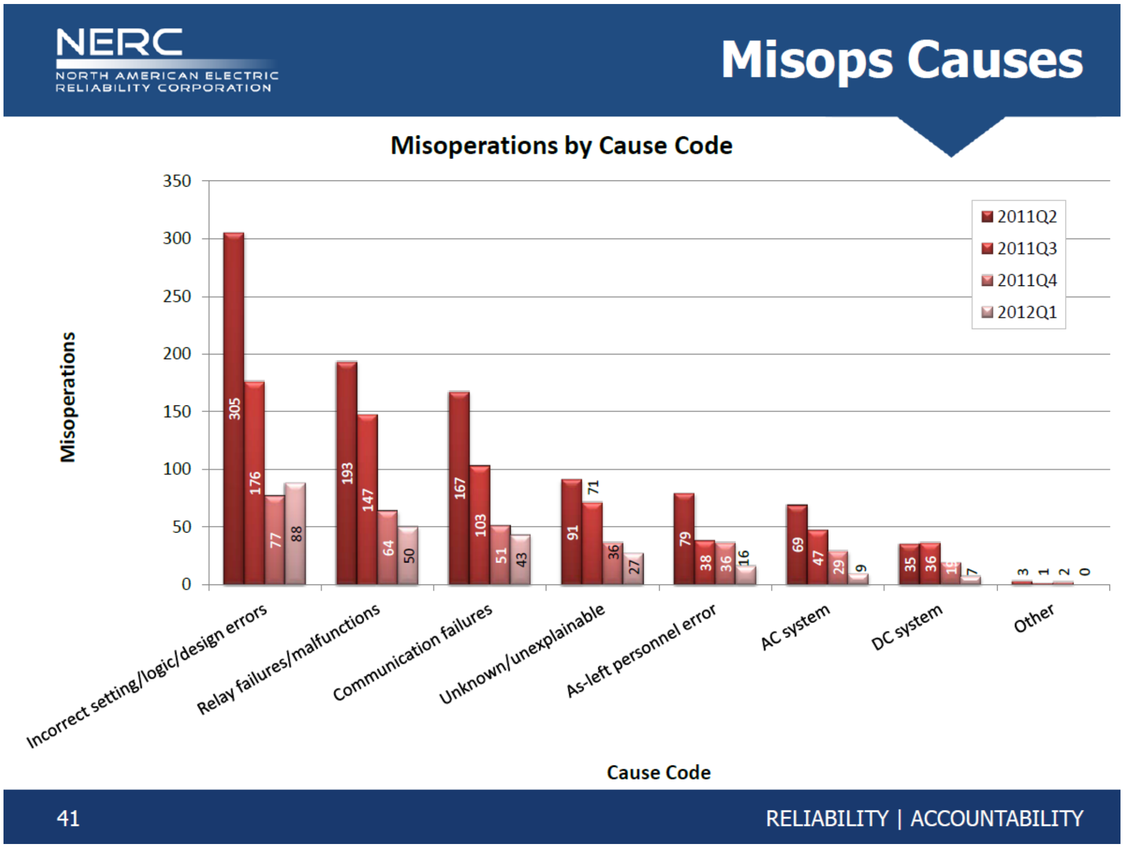


Figure 1: Misoperations vs Cause Code

b. IEEE

Under the IEEE/Power and Energy Society, the Power System Relaying Committee (PSRC) produces guides, standards, recommended practices, and trial-use standards to assist the industry in applying best practices in the relaying community. Standards, recommended practices and trial-use standards provide the requirements for compliance for application in the power system environment. Guides are informational documents that provide more than one way to apply a particular type of protection. These guides document best practices and cover a wide variety of protection practices. It is strongly encouraged to access and reference these documents when designing systems for the protection of the power system. As required by the IEEE Standards Association; periodic updates, new guides, and standards are made available to the IEEE web site and reflect the current technology and practices. A reference list of guides and standards are shown in Appendix E of this report.

c. Manufacturer's Specifications

Manufacturer's specifications are often used throughout the protection scheme design process to aid in the following:

1. Selection of protective relays (specifications, elements, input ratings, output type and rating, extended functionality).
2. Selection of protective relay input sources and outputs (CT, VT, power, output contact wetting and rating considerations).
3. Development of diagrams (layout, AC and DC schematics, connection diagrams, communication diagrams).
4. Development of protective relay configuration or programming (logic diagrams, flow charts, use of manufacturer's software for device configuration).
5. Development of inter-protective relay schemes (transfer trip, zone interlock, trip block, event monitoring, oscillographic triggering, sequence of events recording).
6. Development of inter-systems connectivity and communication implementations (SCADA interface, inter-device information exchange, communication mapping and protocol compatibility).

Achieving a desired protection scheme requires careful selection of the protective relays and control devices. Protective relays, spanning the range from single function to multifunction (often incorporating extended non-protective features), have detailed model numbers (ordering codes) for selection of the elements, power supply voltage, current input rating, voltage input rating, rating and type of outputs, supported communications and many other features. The exact model number for a specifically designed protection scheme is essential. Otherwise, the protective relay or its interconnected systems may not operate as expected.

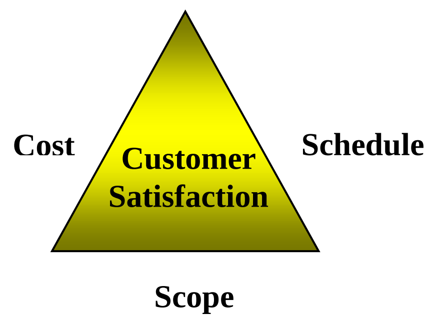
Protection scheme operation, diagramming and configuration are dependent upon the protective relay model number selected. Some manufacturers update multifunction protective relay firmware to add features, improve functionality or to address issues with previously issued firmware. When multiple firmware revisions for a protective relay model number are available, careful attention should be given to ensure the protective relay revision will operate as desired per the protection scheme design. Some design packages specify the allowable firmware version(s) in addition to the model number for the protective relays applied. Manufacturers should be consulted so the impact of firmware revisions for a given model number of protective relay are understood and used as required in the design package.

6. Defining Project Constraints

Most people involved in projects are familiar with the well-known project constraints of scope, cost, and schedule. Customer requirements vary from project to project, but generally, customers will want to optimize project performance in these three dimensions.

The scope of a project generally drives the schedule. The length of a project's schedule is a large driver of a project's cost; therefore, a logical path for project planning is to first define the scope, use the scope to develop a project schedule, and then use the scope and schedule to estimate the project's cost.

The constraints of scope, cost, and schedule must be monitored throughout the project to ensure successful execution of the P&C design process. The Quality Assurance program should consider these issues and prescribe the appropriate practices for course correction (if applicable).



In addition to optimizing project performance within these constraints, there exists the need to recognize additional constraints that may also impact a project, such as the aging work force and training for junior employees.

Employees need to understand how they contribute to the success of the business and be properly rewarded for their efforts. Successful management of the work force can occur through effective forecasting and work schedules for design, engineering, field services, and other important groups within the utility.

It is no secret that the workforce that is tending to the aging electrical infrastructure is also aging and retiring at an increasing rate. As lead engineers, technicians, and crew chiefs retire, their individualized knowledge goes with them. When junior employees become tasked with senior level responsibilities, the professional expertise may be significantly lower. A training and development plan provides appropriate tools and equipment to junior employees, preparing them for challenges, technologies and common issues encountered. The plan would also identify how long after training it takes an employee to reach proficient productivity levels.

7. Defining Schedule

With regards to schedule, time is a project resource unlike others - it cannot be stored, or made to last longer. It cannot be rearranged to suit project objectives - it can only be consumed, whether its value is optimized to benefit the project or not. The challenge, therefore, is to determine the necessary time and schedule to allow the various aspects and portions of a project to be properly designed and implemented.

In many cases, the project schedule for a typical substation or switchyard project is dictated by long lead-time delivery items and the associated engineering required to successfully incorporate this equipment into the power system. The detailed design process to incorporate such major pieces of equipment is often-times straightforward, with few interdependencies and installation details to coordinate.

Protection and control design for a typical substation can involve several panels. The amount of detailed design and the required design schedule is often dis-proportionate to the corresponding relative capital cost. If not addressed at the onset of the project, it is possible that the time line and schedule assigned for the P&C design may not be sufficient to carry out the detailed design per the normal design process.

Project owners, executive sponsors, and other key stakeholders are usually more concerned about project key milestones and the operational "in service" date; how the project design fits into those key dates is generally not of concern to such parties. Additionally, their required project schedule "goalposts" are most often driven by financial considerations (business case, return on investment), regulatory requirements, etc. Functional representation for all major portions of the project (including protection and control) as the project schedule is developed is necessary to make sure that sufficient time has been allotted.

8. Managing Schedules: Implications on Cost and Scope

Despite initial, intentional efforts to accommodate the required schedule and time lines for all elements of a project's design, imposed schedule constraints will often not allow for the normal execution of the detailed design process. In such cases, the project manager may need to consider alternate, innovative means to successfully execute the project.

For example, an execution plan closely coordinated with the installation team can allow design to be released to construction/fabrication before all aspects of the design are complete, so components can be purchased, initial field work can be started, etc. This is generally referred to as fast tracking. This approach would be continuous throughout the project. Compilation of the design changes and interim releases would then be captured at the end of the project resulting in a complete set of record drawings.

However, fast tacking represents numerous risks to the project:

a. Design completeness. For example, were any of the P&C design philosophy elements missed in the detailed design package?
b. Quality Assurance controls are often constrained or even sacrificed in a fast track process resulting in errors, re-design and re-work which can impact cost.
c. Increased costs during construction (fast tracking will invariably lead to cost inefficiencies such as surplus material purchases, re-work on site, stand-by time, etc.).
d. Delays during commissioning resulting in additional costs.

e. Dissatisfaction by the end customer of the final product.

These risks represent a re-alignment of the balance between scope, cost, and schedule, all of which may ultimately have an impact on overall customer satisfaction.

One proactive approach that protection and control design teams could consider in an effort to reduce the schedule or time line is the development of design standards for each P&C scheme. This approach would include logic, wiring, material selection and other such elements. Automated generation of CAD drawings and documents utilizing such standards would also allow for a reduction in the design timeline and still maintain an acceptable level of quality workmanship and Quality Assurance.

When it becomes apparent that a milestone or target date may not be met, the project team should act promptly to address the issues affecting the schedule of deliverables, in order to get the project back on track. The first action should be notification to project owners and appropriate stakeholders indicating the problem is being analyzed by the project team, and that a recommended solution will be available shortly. Potential corrective/recovery measures could include:

a. Review the project schedule to identify sequential activities which could be done in parallel (fast tracking.)
b. Review the project scope for opportunities to delete activities or elements so as to reduce the duration of the required time line.
c. Determine if more resources will facilitate schedule recovery. More resources may include more production from existing resources (for example, overtime), additional resources to supplement existing resources, or the provision of resources that are more productive. Beware of diminishing returns and increasing inefficiencies when considering adding more resources.

If a project's initial schedule is proving to be unachievable, it is likely that cost or scope will need to be adjusted to compensate for the schedule recovery.

9. Applying Design Standards

Use of the word "standard," when describing a utility's protection and control system, often implies a relay scheme or method that is used for a particular application. For example, a utility might apply phase and ground distance relays using directional comparison single-phase tripping of single-pole breakers to protect its highest voltage transmission lines. Several or many of these standards exist for different applications and each standard can be further developed in a way that can be used to improve the quality of a protection and control design package.

Further development of a protection and control standard is achieved when the utility knows in advance what the application will be and is able to specify or preselect the equipment that will be used to protect and control a specific facility or circuit element. The details of equipment specification, layout, configuration, and electrical connections are documented by a set of standard drawings which might include:

a. Schematic drawings describing the overall electrical relationships and configurations of switches, relays, and power circuit breakers.
b. Logic drawings or signal lists further describing internal and external device functionality.
c. Wiring drawings or lists facilitating construction.
d. Layout drawings describing physical arrangement which might include fabrication, assembly, and installation details.
e. Material lists with material descriptions pre-specifying the chosen off-the-shelf equipment used to satisfy the utilities protection and control objectives.
f. Checklists of deliverables ensuring a comprehensive design drawing set.

These standard drawings can be used as a template to make site specific drawings which can then be modified if necessary to accommodate site specific peculiarities. It is a different problem to apply a standard as part of an addition to an existing facility than it is to apply the standard to an entirely new facility. Interfacing with legacy equipment may require some adjustments or further equipment replacements.

Knowing in advance the switchyard arrangement, the switchyard voltage level, and the types and models of power circuit breakers, instrument transformers, protective relays, controllers, racks, switches, connectors, and telecommunication equipment, can help the designer determine how to develop the drawing set for a particular standard, and which standard should be used for a particular project. Different protection and control designs are developed for lines than for transformer banks, shunt capacitors or shunt reactors. For example, knowing that (1) a line will terminate in two breakers, (2) be protected by redundant relays, each connected to separate CT secondary circuits, and (3) that each breaker pole has two trip coils, each separately fused, can help the designer predetermine the necessary wiring. Prediction of methods used to maintain in-service equipment can be used to determine methods for isolation and equipment layout. Relay racks can be pre-configured with terminal rails to enable future interconnection of control cables providing interface to other relay racks. These may include switchyard devices such as fault recorders, event sequence displays, termination or cable-shield grounding frames, instrument transformers, and power circuit breakers.

When standards are used along with a process for continuous as-built improvement, best quality and efficiency can be achieved. Lessons learned during commissioning of an installation at a previous facility location can be used to change the standard details provided on drawings to avoid repeat errors. Some problems may be site specific and cannot be avoided. Often times a utility will not accept a particular standard at the point of interconnection between utility's and some modifications are therefore necessary. Some re-wiring might be necessary to match relay settings, CT ratios, etc.

The standard design might specify how redundancy is provided, how flexibility for long term operation and maintenance of the protected, energized facility is achieved, and what method is prescribed for unique identification of circuit elements and switchyard devices.

Once standardized equipment has been in operation, adjustments can be made for items such as: clearance for switchboard tag supports; switch or meter height-above-the-floor; device clearance adjustments; spare blocks for future wire changes or cable attachments; extra room for maneuvering test equipment; and proper identification language on nameplates. If certain methods for isolation and testing of equipment are standardized, then standard drawings can pre-define the agreed upon layouts, and electrical connections.

Separate teams are often used to plan, design, construct, commission, operate, and maintain a facility. Use of standards minimizes design time and eliminates differences due to personal preference. When standards are used, each team knows what to expect of the other teams because methods are predefined by collaborative decision. This enables efficient use of tools, efficient training, adherence to safety procedures, and fewer change orders during installation. Consistency is established between like-functioning equipment at different locations. A reliable, well designed protection and control standard helps the utility meet reliability objectives in avoiding unplanned outages caused by human error or component failures. This is partly because complexity of electrical interconnections and the mechanical arrangement of equipment impact the human performance of operation and maintenance tasks. Continuous improvement of the standard assures that discovered errors are not repeated at like-functioning facilities.

Examples of design errors which could affect multiple projects include: wiring errors or dimensioning errors shown incorrectly on drawings; illogical or poor equipment layout; errors of design calculation for relay settings or input/output configuration; errors of design concept; insufficient or incorrect documentation; use of an incorrect color code to identify cable-conductors; incorrectly specified cable lengths; wrong source or destination locations; not knowing the cable tray and rack location or method; inability to transport preassembled equipment thru the building entrance; incorrect or unsafe cable shield or conductor grounding; insufficient worker clearance around installed equipment; and not accounting for changes to vendor products over time. Use of a standard can help reduce design errors on a project when a third party designer is in the process of learning a particular utility's methods.

Use of the generic standard as a basis for each project reduces the number of implementation methods conceived by different designers or planners intended for different, but functionally equivalent facilities. These basic drawings describing the standards must be continuously maintained and improved in order to achieve these quality improvements.

10. Importance of Site Visits

With the increased emphasis on engineering projects delivered on time and on budget, assuring that the quality of the issued construction design package is an important part of the protection and control engineering process. One way to improve Quality Assurance is by including site visits in the engineering process. Whether located in the office or in the field, the design engineer should not rely solely on drawing records. Instead, a site visit is recommended before detailed design begins. A site visit will help develop an accurate scope document by field-verifying site conditions, comparing record drawings to the actual installation, and verifying equipment ratings per nameplate data. An accurate scope document is a critical part of the Quality Assurance process.

At the first site visit, Protection and Control Engineering (P&C engineers, designers, and/or supervisors), Substation Operations (operation manager or supervisor) and Field Engineering (relay testing, technicians and/or supervisors) should meet at the substation to review project specific details. It's important for all stakeholders in the project to meet and agree upon a design approach and scope considering constructability. Following this meeting, protection and control, Substation Operations, and Field Engineering will have aligned their expectations regarding all high level aspects of the project. Photos should be taken to assist in the writing of the scope document.

A second site visit provides P&C engineers and designers an opportunity to more closely examine the substation where their design will be implemented. The engineers will gather all field information necessary to complete the final engineering package. This will include checking the station drawings with the existing field conditions to avoid errors due to missed record drawings from prior projects. Photos should be taken once again to assist in the finalizing of the engineering drawing package.

A third site visit should be held for Protection and Control Engineering, Substation Operations, Field Engineering, and the Project Manager, to review the engineering design package in the field and confirm the design's constructability in accordance with the Project Manager's time line.

11. Checklist

A P&C engineering design package is a comprehensive set of prints and related documents that describe how the P&C system is intended to be built and operate, the specifications for its constituent elements, the basis for the relay settings, and (when applicable) provisions for future expansions to that system. A P&C engineering design package has many parts and features, some technical in nature and some non-technical, that must be accurate in order for the package to be considered a quality package. Some examples of technical features include:

a. The elements on the one line diagrams are accurately reflected in general layout,
b. The functional accuracy of the components per manufacturers' recommendations and the required client specifications are accurately reflected in the schematics;
c. The wiring diagrams align with the schematics;
d. The cable schedules align with the wiring diagrams.

Some examples of non-technical features that must be correct may include:

a. Title block, revision block, electronic block (such as CAD software block of a device)
b. Border, index, font, color, layer and version of the electronic file.

Failure of either technical issues or non-technical issues can result in a P&C package lacking the quality required to ensure that the P&C design meets the requirements of the project and / or customer.

To ensure that all features of the P&C design package are included in a QA/QC process, the desired features as prescribed in the performance / functional specifications should be translated into a listing that can be used to facilitate the review process. A checklist is a type of this review aid capturing all such features as well as activities and tasks, thus minimizing the chance of key design elements being missed in both the design and the review processes.

A common practice is to have signature blocks at each step of a checklist. As each step in the checklist is completed, the person performing the check would physically sign the checklist acknowledging that step is complete. This signature serves two purposes. First, the signature provides a historical record that the check was completed and by whom. Second, the signature assigns personal accountability to that design element or task.

A checklist should be considered as a dynamic design tool. Each time a new type of error, design feature, activity or task is identified, the checklist would be updated thus reducing the likelihood that the same design error re-occur or that the same new design feature be missed with the next engineering design package.

12. Clouding and Demolition

Modifying existing protection and control systems by replacing components and devices in a phased-in approach requires a comprehensive understanding and knowledge of the protection and control schemes being impacted, as well as the risks and consequences of an inadvertent trip while modifying the panels. A detailed demolition and installation plan can be developed to install the new devices without compromising the integrity of the protection and control functionality while also minimizing the chance of an adverse impact on the in-service operations.

The most effective method to achieve these objectives is to prepare separate demolition and installation design packages. Demolition drawings contain only that information that is related to the disconnection and removal of panel devices or wiring. Such changes can be difficult to accurately convey only using “clouds” around the affected areas. An example is a connection that is not wholly removed but simply moved to another point of the drawing. This can result in a wire being cut based on the removal print, only to discover it needs to be added back in the next drawing.

To develop a demolition drawing, start with the updated record drawings. Then mark or highlight all removals (equipment and cabling) with a unique color marking (e.g. green) and all wiring disconnections that are to be re-used with a different color (e.g. yellow).

A unique color marking can be used to highlight additions, augmenting the use of clouds, or instead of using clouds if their use would make the drawing too cluttered. These installation drawings will become the record drawings once the work is completed.

These demolition and installation packages could also include a written step-by-step sequence, depending on the complexity of the work, the opportunity for protection misoperation and the need to minimize time for commissioning.

13. Point-to-Point Checks

The point-to-point check is a recommended design practice used to produce a quality set of drawings prior to field issue. The point to point check is a meticulous process in which the designer uses a colored pencil or highlighter to mark or trace the intended wiring endpoints shown on the schematic diagram to verify that an equivalent connection is shown on the wiring diagrams. This process ensures that the wiring diagrams accurately portray what is shown on the design schematic so that all points of common potential will be properly connected and all other points will be properly isolated from each common connection. The highlighter is used to account for each endpoint of each line of the schematic as it is verified one-by-one that each endpoint is properly shown as a connection on the wiring diagrams and that no other erroneous connections exist.

Without this point-to-point process, drawings could be issued to the field with wiring errors of equipment or protective schemes. Unplanned outages could occur if these errors are missed by the field technician during the checkout process.

Every component of the design package should have a point-to-point check performed. This process does take some time and should be included in the project schedule. Doing so enables a quality design package demanded by the client.

14. Peer Reviews

In the course of project execution any competent design engineer or other professional can, at times, introduce design or document preparation errors or omit prescribed design features. This can happen as the original designer responsible for the related design scope becomes familiar with their design package and overlooks design errors. Peer reviews are an important step in any QA/QC process intended to minimize such errors or omissions from being incorporated into the final design package. The concept of a peer review is to involve person(s) qualified and competent in the topic of interest in the review of the engineering design package to identify any errors or omissions through impartial evaluation.

A peer review does not guarantee that any and all design errors or deficiencies will be identified prior to issuing the final design package. To minimize the possibility of errors getting through this review process, the peer reviewer needs to be suitably equipped to carry out the design review. The peer reviewer requires resources and information, such as:

a. A specific scope of the review. For example, a peer reviewer might be asked to only review the schematics for functional accuracy and not perform a point-to-point wiring check.
b. Sufficient time to perform a comprehensive review.

It is important to note that a peer review does not remove responsibility from the original designer but should be used to improve the overall quality of the end product and resolve any issues identified in comments and markings.

15. Preparing As-Built and Record Drawings

Good drawing management is a critical part of a Quality Assurance process. Operators, technicians, engineers, and managers must all have confidence the available drawings properly represent the installed equipment. Accurate drawings reflecting the actual equipment and systems design are vital to the protection and control schemes since the consequences of erroneous operation of P&C schemes could be detrimental.

Drawing errors are often identified during the transition from installation and commissioning to operation. Construction drawings must be marked up by the installation team to "as-built" state to show how the installation was actually built. These corrected drawings should be submitted back to the document management team for inclusion in the final system records, which become tools used by the operations and maintenance staff.

As-built drawings should include information on how the protection system was installed and what changes were made during the installation. All modifications and additions made to the original design should be clearly indicated on a revised clean set of construction / installation drawings, via manual mark-up of the physical drawings or revisions to the electronic files. This as-built information would then be transferred carefully to a final set of record drawings for that design. Any additional changes discovered during installation or commissioning should be captured on these drawings and not those used for the demolition work.

Record drawings are important for at least two primary purposes. First, they are a record from which future system modifications and additions should be designed. It is important to ensure that as-built drawings are completed and become record drawings as soon as a project is finished, especially if a second project is to follow in the same substation as soon as the previous project is completed. Secondly, these drawings are valuable for the operations and maintenance staff. There may not be enough time to verify correctness of drawings during an emergency situation; therefore, it is vital to have a correct set of final record drawings at the site for the staff to use.

To ensure good Quality Assurance practices, all projects should have as-built drawings included in the scope of work. One of the project participants should be accountable for documenting all changes and developing record drawings.

16. Measurement and Improvement

Quality assurance refers to the processes developed and implemented to support the repeatability of tasks and activities related to an effective P&C design. Key to any QA process is the means by which the effectiveness of the processes and performance of those implementing the processes are to be measured. This measurement has two key inputs:

a. Metrics

   Metrics are those elements of the P&C design process that should be measured to assess the effectiveness of the processes. For P&C Design, these could include:

   i. Number of review iterations before releasing a design package to construction or procurement
   ii. Number of Construction or Manufacturing Change Notices related to design variances or deficiencies
   iii. Variances in the project budget (overall or by task / activity)
   iv. Deviation from the project schedule.

b. Key Performance Indices (KPIs)
   KPIs can be set as part of the Project Quality Plan or more generally as part of a company's over-arching Quality Management System. KPIs are the stated acceptable targets for each metric.

Verification and validation of a P&C design are key elements of the Quality Control program developed to implement the QA processes and to identify improvements to these processes that would be applied to future projects. Verification assesses the alignment between the design and the Project specifications while validation assesses the effectiveness of the designed system in achieving the intended outcomes. These two activities will drive improvements in the QA Program and processes through Non-Conformance and Corrective Actions.

17. Conclusion

The goal of a Quality Assurance Program is to prevent defects or problems from occurring and, equally important, from reoccurring. Management and third-party auditors are usually responsible for establishing quality assurance standards, checklists, relevant documentation and audits of internal processes.

A guideline has been prepared to assist in the development of a Quality Assurance Program for Protection and Control design. This guideline can be used as the basis for new or revised procedures and processes that, when consistently applied, should result in accurate P&C designs.

APPENDIX A

EXAMPLE OF NERC ADVISORIES HIGHLIGHTING THE CONSEUQNCES OF THE LACK OF QUALITY ASSURANCE

Example 1: During a substation project, the construction team failed to use the latest version of a construction document to complete the installation of a protective relay system. The most recent version of the document had incorporated a configuration change to the CT ratio for the protective relays. Because the team used outdated documentation, the incorrect CT ratio was configured for the relaying. During commissioning, the team failed to detect the error, since their testing reference was to the outdated documents. The Protection System equipment was placed into service with the wrong CT ratio and then sometime later tripped improperly during a system disturbance. *(Taken from the NERC Industry Advisory, November 8, 2011)*

Example 2: An engineer (ENG) and engineering tech (ET) worked together on a project at a 1940's vintage power plant replacing ten 115kV breakers. This project was not replacing any protective relays or performing any other upgrades other than the breaker replacements. All of the new 115kV breakers were identical breakers and the company's current standard. The design job was very repetitious. The breakers were laid out in a breaker and a half configuration. However, some of the breakers were normally open such that system operations could control the power flow in a specific direction. During design, at least one of the breakers on one of the buses had a bus differential CT that was wired non-polarity but it should have been wired polarity. The problem happened because of some confusion on how the drawings were laid out and it was hard to determine which direction was the protected zone. The ENG and the ET incorrectly connected the CT's such that as soon as current flowed into the circuit, the differential relay would see current and trip the lockout which would in turn, trip all breakers on the bus. Given the substation configuration, a trip of the bus would trip off one of the generators. When the field technician put the scheme into service, the differential operated and a 125MVA generator was tripped off line. The engineer and ET did perform quality control on the project. However, the QC was based upon doing a wiring check via a point-to-point. There was not a schematic review performed. The ENG only had about 1.5 years of experience and the project should have been reviewed by a senior level engineer. The ET was not at a skill level to know if the CT's were connected correctly.

Example 3: A test engineer was the lead on commissioning a new 500kV line relay protection scheme. The project involved replacing the primary and secondary line protection relays on two different lines. There were many problems with the design package that was issued from engineering. The engineering design packages lacked a proper quality control check. Engineering lacked the expertise and familiarity of dealing with protection schemes at that voltage range. Fortunately this did not lead to an outage but there was a substantial time spent correcting the prints in the field before commissioning. The budget for this installation package was greatly impacted as a result. This also could have led to an operating system problem as there was a small window for the outages to take place.

The first problem was the original 500kV relays were installed in the early 1970's. Engineering had not designed a new or upgraded 500kV relay package in nearly 30 years. The next problem was attributed to the fact that Engineering finalized the one line very late in the design process. This led to a very short time being spent on the QC of the final design. The final problem was related to a company culture or philosophy that had been slowly evolving yet negatively impacting the QC process. The Engineering department relied heavily on the test engineers in the field to catch any design errors. The mindset was to get the prints to a certain acceptable error level and the test engineer would be able to troubleshoot and/or redesign in the field if necessary. With complexity of this project this philosophy greatly impacted the commissioning schedule.

The test engineer had to perform several modifications to the design in the field. The changes involved modifying CT connections and control circuits. There were also many devices incorrectly removed or added. This problem was attributed to the fact that engineers involved in the final design did not understand the old scheme well enough to know what needed to be removed and what needed to stay. The test engineer was able to work out the design issues and commission the two 500kV lines.

If there had been an adequate QC process many of the problems could have been averted prior to reaching the field. Additional test engineers had to be brought in to help finish the project due to the lack of a QC process. Also, the exact line commissioning date had to be moved several times because of the many changes to the original schedule. This also consumed operation resources each day of delay and resulted in a new study for a re-energized approval each day. Ultimately, this led to the commissioning of the lines early on a weekend morning because of system conditions and concerns.

APPENDIX B

SAMPLE CHECKLIST 1

DESIGN		DATE	
CHECKED		DATE	
APPROVED		DATE	

ITEM No.	DESIGN ELEMENT	PHASE OF ENGINEERING DESIGN				NOTES
		1	2	3	4	
1.0	**Project Definition Docoment**					
1.1	Conceptual One - Line Diagram					
1.2	Project Technical Specifications					
1.3	Phasing Diagrams					
1.4	Conceptual Layouts					
2.0	**P&C Design Definition**					
2.1	P&C Single Line Diagram					
2.2	P&C Design Narrative					
2.3	Teleprotection / Telecontrol Design Narrative					
2.4	Communications Block Diagram					
3.0	**Relay Specifications:**					
3.1	Bid Packages					
3.2	Proposal Evaluations					
3.3	Procurement and Expediting					
3.4	Vendor Shop Drawing Approvals					
4.0	**Control Room Layouts (A-B systems):**					
4.1	A-B Systems segregation per regulatory rules?					
4.2	Room allowance around panels for commissioning and maintance access?					
4.3	AC / DC Distribution Layouts Completed?					
5.0	**Building Systems Monitoring and Alarms:**					
5.1	Fire detection					
5.2	Security and surveillance					
5.3	HVAC					
5.4	Communications					
6.0	**DC Power for Equipment:**					
6.1	Circuit alloction for relays, controls					
6.2	Existing battery bank / charger ratings and capacity checked?					
6.3	New battery bank / charger ratings and specifications					
7.0	**Field Wiring:**					
7.1	Cable routing					
7.2	Termination details					
7.3	Cable specifications					
8.0	**Drawings:**					
8.1	DC Schematics					
8.2	AC three line drawings					
8.3	Equipment wiring drawings					
8.4	Interconnection wiring drawings					
8.5	SCADA / RTU Layouts					
8.6	SCADA / RTU Wiring Diagrams					
8.7	Communications Wiring Diagrams					
9.0	**Relay Configuration:**					
9.1	Protection settings completed					
9.2	I/O logic assignments completed					
9.3	Internal protection and control logic programming completed.					
9.4	Setting / configuration files sent to commissioning team					
10.0	**As-Built / Record Drawings:**					
10.1	Received clean red-lines from field					
10.2	Received "as-commissioned" relay setting / configuration files					
10.3	Changes updated on drawings and operating diagrams					
10.4	Changes updated in relay setting / configuration files					
10.5	Drawings signed-off and certified with seal of the responsible engineer					
10.6	Final relay setting / configuration files issued to field / operations.					
10.7	Final drawings issued to Document Control					

ENGINEERING DESIGN PHASES	NOTES
1. Preliminary / conceptual design	Can be in support of project planning phase, system planning or Front-End Engineering Design (FEED) phase
2. Detailed Design	
3. Issued for fabrication / construction	Final check before releasing to vendor or contractor
4. Close-out	Confirming that all design elements have been completed, final as-built / record drawings completed. This check is completed after the new system has been fully commissioned and in service.

SAMPLE CHECKLIST 2

Date Submitted to Sponsor ______________________________

Dwg Package Transmittal Date:

Checked		Section	Description	Project Engineer - Sign Off	Control Reviewer	Physical Reviewer	Civil Reviewer	SPE	Comments
					Responsibility				
	1	**Index Sheet**	Always provide complete index sheet with package following EDG-A.01-002. App'd and Cert. Eng., Designer and Checked By names should be complete on both internal and consultants projects. Verify all drawings and corresponding revision listed on index sheet are included in package.		X	X	X		
	2	**Circuit Diagram**	Review Circuit Diagram internally following checklist provided in EDG-B.01-003, 004. If secondary limitation information for equipment and legend has not been updated, check with CMT sponsor to see if it needs to be completed on current project. Make sure circuit diagram and Metering and Relaying diagram match.		X	X		X	
	3	**Location Plan**	Review Location Plan internally following checklist provided in EDG-B.02-005. If new substation or expansion to existing, review Location Plan per EDG-B.02-003. Verify line numbers have been included on all Xcel Energy lines. Correct naming of "Control House" to "Electrical Equipment Enclosure" on all related drawings. Use NH (22x34) drawing format for all layout and section drawings with appropriate scale and plan North arrow should always be designated up or to the left. Make sure that phasing follows the ED 40101. Confirm the phasing of the incoming t lines			X			
	4	**Electrical Layout**	Review Electrical Layouts and Sections internally following checklist provided in EDG-B.03-003. Verify all electrical clearances with new equipment. Verify adequate views are included. Confirm phasing of breakers 1-3-5 on A-B-C			X			
	5	**Material List**	Review Material List internally following checklist provided in EDG-B.09. Make sure Material List is following current master in Projectwise. If not, follow EDG-B.09-002 to update existing list.			X			
	6	**Grounding Layout**	Review Grounding Layout internally following checklist provided in EDG-B.05-003. Does the Ground Grid Data exist on layout? If not, check with CMT sponsor to see if has to be included or updated early on in engineering/design process.			X			
	7	**Control & Lighting Layout**	Review Control & Lighting Layout internally following checklist provided in EDG-B.06-003.			X			
	8	**Cable & Conduit List**	Review Cable & Conduit List internally following checklist provided in EDG-B.08-001. The Cable & Conduit List (Examples).xls spreadsheet located in the PW folder "Files used during Projects" indicates how Xcel Energy prefers to show/label the cables and conduits. This is a great reference when completing a project and should be used for consistency			X			
	9	**Electrical Equipment Enclosure**	Review EEE internally following checklist provided in EDG-B.07.			X			
	10	**Topography**	If this is a new substation a topography and property plat needs to be created. Verify that these was transmitted and filed in ProjectWise.				X		
	11	**Contour and Grading**	The Contour and Grading drawings should match the layout of the Location Plan. The physical designer should always put the Contour and Grading drawing into the Site Plan to verify that the civil and physical drawings match.			X	X		
	12	**Foundation Plan**	Compare the Foundation Plan to Electrical layout to verify the column rows and location of slabs and piers match. Do the details show the anchor bolt spacing and does this match the vendor drawings, is the schedule complete and the information listed correct.			X	X		
	13	**Electrical Equipment Enclosure Foundation**	Compare the Foundation drawings to the Electrical Layout to make sure the openings match up to cabinet locations or A.C. ducts. Are the dimensions correct? Is it shown with the same orientation as shown on the location plan? Are the details shown correctly?			X	X		
	14	**Steel Arrangement Plan**	If there is a Steel Arrangement Plan check to see if all the stands are shown and the schedule lists what sheet they are detailed on. Check the orientation of the stands as indicated by the arrows to make sure they match the Electrical Layout Drawings (arrows are on the side as shown on the detail sheet).			X	X		
	15	**Steel Erection Drawings**	Check to see if the piece marks match the detail sheets. Compare these drawings to the Electrical Layout Drawings to verify beams are at the correct elevation. Does the layout match the Foundation Layout drawings?				X		
	16	**Steel Details**	Compare the Steel Details to the Electrical Layout Drawing to assure that all the equipment mounting locations are correct. Are the pieces listed correctly on the schedule? Is there a bolt list indicating bolt size for assembly of the structure?				X		
	17	**Rolled Steel**	Compare equipment and bus support stands to the master drawings. If there are any changes made to these they should have a different set of calcs listed with a different NX number than the masters. Are all the mounting dimensions listed and match the vendor drawings? Are quantities correct? Was the master that was used current and the calculations up to date?				X		
	18	**Taper Tubular Steel**	Compare the design to the Electrical Layout Drawings to see if equipment mounting and spacing match. Are the elevations correct? Do the details match up to the erection drawings? Do the materials match what is listed in the schedule?				X		
	19	**Oil Containment**	Check to see if the drawings match the Electrical Layout Drawings. Does the drawing show how much to pitch the slab and show direction of pitch? Is the drain shown? Compare to the master drawings to see if all details are shown.				X		
	20	**Electrical Equipment Enclosure**	Review EEE. Do they match the standards as listed on the master drawing? Are the details shown correctly?				X		
	21	**Vendor Drawings**	Have all vendor drawings been filed in Project Wise? This should include all design calculations.			X	X		
	22	**General**	Have masters been utilized on this project as appropriate?			X	X		

SAMPLE CHECKLIST 3

The Control Engineers are to check and make sure that the person responsible or the gatekeeper has done the required tasks before the Project Passport WO is closed.

TASK		**Person Responsible**	**Gatekeeper**
☐	Control dwg field rev. received.	Drafter	
☐	Substation one-line diagram rev. received.	Drafter	
☐	Operating system diagram revised.	Designer	
☐	Relay setting files returned to Outlook mailbox.	Engineer	John Doe
☐	Relay configuration files filed on file management system server.	Technician	Jane Doe
☐	System Simulator check done on the area.	Engineer	
☐	Breaker / Line / Transformer / Power Line Carrier Frequencies data updated.	Engineer	John Doe
☐	Relay setting documentations filed on file management system server.	Engineer	
☐	Relay setting at remote substations are done and implemented before energizing.	Engineer	
☐	Programmable Logic Control programs filed on file management system server.	Technician	Jane Doe
☐	PLC program and logic pdf prints are sent to field.	Engineer	
☐	Human Machine Interface programs filed on file management system server.	Technician	Jane Doe
☐	PLC/HMI program copied to CD and sent to field.	Engineer	
☐	Relay setting and configuration files deleted from Outlook mailbox.	Engineer	John Doe
☐	Send note to various gatekeepers that the project is being closed out so they can make sure they have processed (or request from the field) project data.	Engineer	
	• Relay Setting System		John Doe
	• Trip Switch		Jane Doe
	• Configuration, Load check, other reference files		Jane Doe
☐	If engineering is changing the device name for a ABC relay, John Doe need to be notified so he can update the master setting database.	Engineer	Jane Doe
☐	Check with relay technician project punch list to make sure everything that is needed to be done is done.	Engineer	

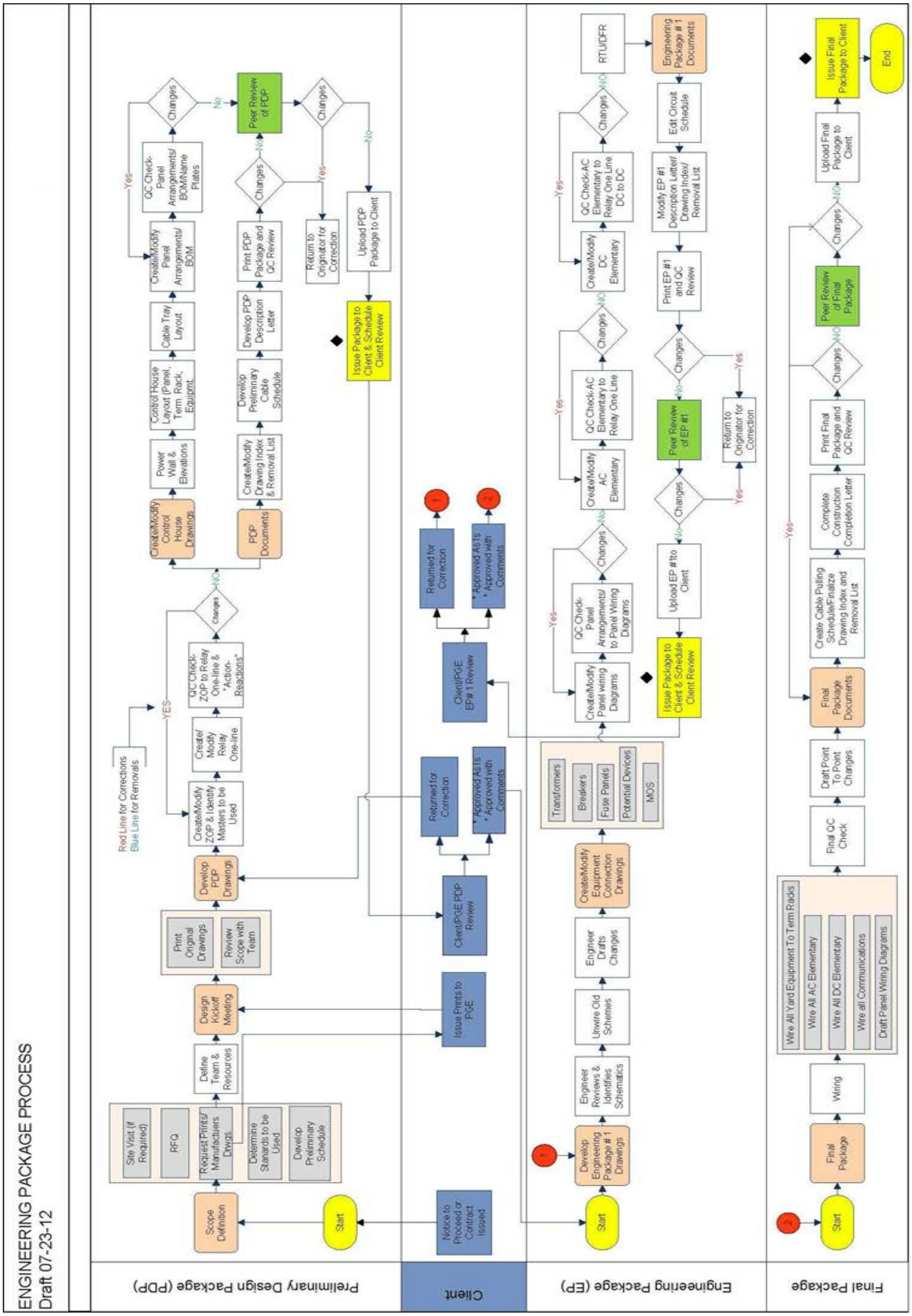
APPENDIX C

SAMPLE REQUEST FOR INFORMATION (RFI) FORM

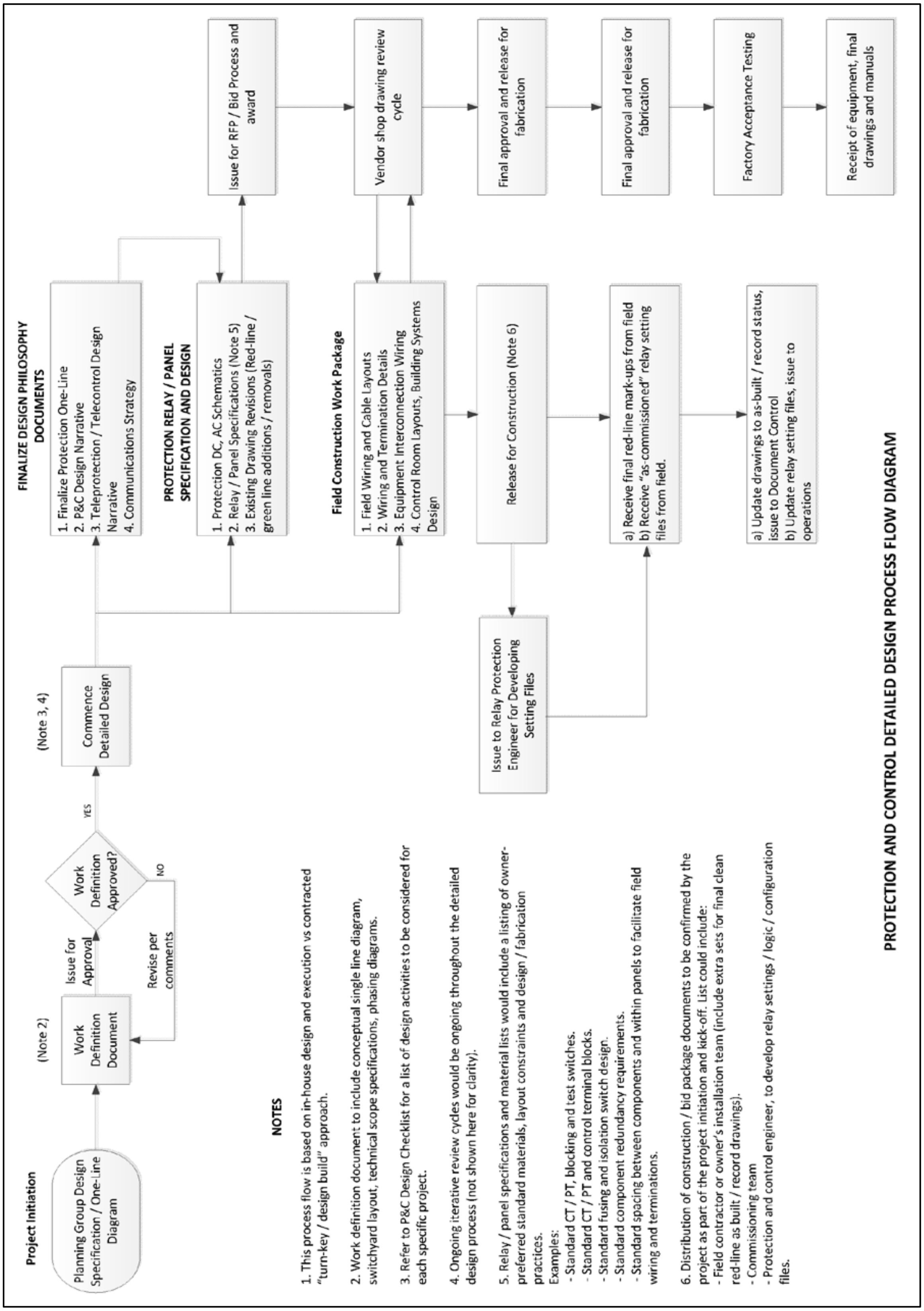
Author: *William Durie*			Project Name: STA 126 HOPKINTON			
Contact: jrodriguez@powergridmail.com			Project No:			
Date:			Recipient: Michael Brigandi			
Item #	**Assigned To**	**Reference**	**Comments/Issue**	**Response Need Date**	**Status**	**Response**
1	Michael		Could you send me NSTAR's transformer loading philosophy? Emergency loading philosophy.		Closed	Received email from Mike and forward to Russ on 12-28-11. Support stored in "STA 126 HOPKINTON\Request for Information\Item 1" 12/ requested DXT file, forward to Mike
2	Michael		During the site visit you mention this station has xfmrs normally run in parallel. Can you confirm this? Do you have substation operation instructions that would describe the normal operation of this station?		Closed	12-28-11 see item 1
3	Michael		Will you be re-using the existing cables going to transformers 110A and 110B or will you pull new ones. Need confirmation that we will be pulling new cable, as mention on conference call on 12/19/2011, and that cables will be name base on current standards.	12/23/2011	Closed	12/28/11 - please design to replace new cables. Whether to reuse ca field decision later in the game.
4	Michael		Please provide existing cable schedules for Hopkinton substation.	12/23/2011	Closed	12-28-11 - I am currently having trouble finding an old cable schedule use the standard cable schedule and build off it using the XFMR print given you.
5	Michael		Drawing 126-87 is missing from drawings provided by NSTAR and it will be needed as part of this design. Please provide drawing.	12/30/2011	Closed	12-28-11 I don't believe this drawing 126-87 was ever used for anythi in the drawing index you will see it says 'reserved' for its description. you think it is active? Did you see a reference to 126-87 in another dr could be a mistake. 12-28-11 PGE looking into it. 1-10-12 I've asked update me. 1-7-12 Says PGE is looking into it. Any final word? 1-16-2 not need this drawing this may have been a mistake
6	Michael		Please provide manufacture drawings for new 13.8kV, 3000A breaker to be install.	12/30/2011	Pending	12-28-11 We are supposed to have the cad drawings for the breaker will send it off as soon as I get it. 1-10-12 - Checked in with Ruvani, s waiting for the drawings. Hopefully they will come this week. She will soon as she gets them. 1/7/12 Checked in with Ruvani, she is still wa drawings. Hopefully they will come this week. She will alert me as soo gets them. 1-16-12 Manufacture drawing still not in.
7	Russ		What CT's ratio will be used for Bus Diff scheme 2000/5 or 3000/5 with taping on 2000/5	12/30/2011	Pending	This is assigned to Russ P. 1/7/12 Will have to get back to you on thi 12 - Requested Excitation characteristics of feeder 2000/5 CTs from ITEM 19)
8	Michael	126-59(Old Transformer)126-129, 126-2004-2(New transformer)	Determine if 63T permissive will be used on the new Transformer. We use 63PFX contact of new transformer instead (See dwg. 126-129). Please confirm. 1-20-12 - see ITEM8.pdf in the old xfmr 63T had an auto reset functionality. 86TA supervised the reset circuit. The new xfmr has a manual reset 63FPX. I think the 86TA contact can be spared.	12/30/2011	Pending	1/7/12 Glen was going to get more information on what exactly they w for here. If the 63T is for sudden pressure we want to trip on that.
9	Michael		are any of the CCVT's being changed out?	ASAP	Closed	Per Ruvani there is no plans to change out any CCVT's. 1/7/12 See a email. Ruvani is not installing any new CCVT's at Hopkinton.

APPENDIX D

SAMPLE QA FLOW CHART 1



SAMPLE QA FLOW CHART 2



APPENDIX E

IEEE Standards List

No.	Title
C37.101	Guide for Generator Ground Protection
C37.102	Guide for AC Generator Protection
C37.103	Guide for Differential and Polarizing Relay Circuit Testing
C37.104	IEEE Guide for Automatic Reclosing of Line Circuit Breakers for AC Distribution and Transmission Lines
C37.105	Standard for Qualifying Class 1E Protective Relays and Auxiliaries for Nuclear Power Generating Stations
C37.106	IEEE Guide for Abnormal Frequency Protection for Power Generating Plants
C37.107	Digital Protective Relay Sys Interface
C37.108	IEEE Guide for the Protection of Network Transformers
C37.109	Guide for the Protection of Shunt Reactors
C37.110	Guide for the Application of Current Transformers Used for Protective Relaying Purposes
C37.111	IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems
C37.112	IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays
C37.113	IEEE Guide for Protective Relay Applications to Transmission Lines
C37.114	Guide for Determining Fault Location on AC Transmission and Distribution Lines
C37.116	Guide for Protective Relay Application to Transmission-Line Series Capacitor Banks
C37.117	Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration
C37.119	Guide for Breaker Failure Protection
C37.230	Guide for Protective Relay Applications to Distribution Lines
C37.231	Recommended Practice for Microprocessor-based Protection Equipment Firmware Control
C37.232	Recommended Practice for Naming Time Sequence Data Files
C37.233	Guide For Power System Protection Testing
C37.234	Guide for Protective Relay Applications to Power System Buses
C37.235	Guide for the Application of Rogowski Coils used for Protective Relaying Purposes
C37.236	Guide for Power System Protective Relay Applications over Digital Communication Channels
C37.238	IEEE 1588 Profile for Protection Applications
C37.239	Standard Common Format for Event Data Exchange (COMFEDE) for Power Systems
C37.242	Guide for Synchronization, Calibration, Testing and Installation of Phasor Measurement Units for Power System Protection and Control

C37.243	Guide for Application of Digital Line Current Differential Relays Using Digital Communications
C37.244	Guide for Phasor Data Concentrator Requirements for Power System Protection, Control and Monitoring
C37.90	Standard for Relays and Relay Systems Associated with Electrical Power Apparatus
C37.90.1	IEEE Standard Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus
C37.90.2	IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers
C37.90.3	IEEE Standard Electrostatic Discharge Tests for Protective Relays
C37.91	Guide for Protecting Power Transformers
C37.92	Standard for Low Energy Analog Signal Inputs to Protective Relays (1331)
C37.93	IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels
C37.94	IEEE Standard for N times 64 kilobit per second Optical Fiber Interfaces Between Teleprotection and Multiplexer Equipment
C37.95	IEEE Guide for Protective Relaying of Utility-Consumer Interconnections
C37.96	IEEE Guide for AC Motor Protection
C37.97	Guide for Protective Relay Applications to System Buses
C37.98	Standard Seismic Testing of Relays
C37.99	IEEE Guide for the Protection of Shunt Capacitor Banks
C57.13.1	Guide for Field Testing of Relaying Current Transformers
C57.13.3	Guide for Grounding of Instrument Transformer Secondary Circuits and Cases
PC37.118.1	Standard for Synchrophasor Measurements for Power Systems
PC37.118.2	Standard for Synchrophasor Data Transfer for Power System