THE COMMISSIONING PROCESS FOR
NEW SUBSTATION EQUIPMENT & PROTECTION SCHEMES
ON THE BULK ELECTRIC SYSTEM

Lawrence P. Hayes
FirstEnergy Corp.

ABSTRACT

This paper discusses the various aspects, considerations, and technical requirements involved in commissioning new substation equipment and protection schemes installed on the Bulk Electric System (BES). The current highly regulated environment in which utilities operate call for a very dedicated and precise commissioning process. This mostly pertains to the addition or modification of protection schemes, especially those schemes associated with interconnected facilities. Utilities today are more and more likely to use vendors for engineering, construction, wiring, and testing. This mix of vendors interacting with the internal workforce often produces a climate of uncertainty when it comes to insuring the integrity of the new installation. It is imperative that each utility company designs a commissioning process that addresses these potentially volatile situations.

INTRODUCTION

The importance of a well thought out and executed commissioning process cannot be overstated given the current environment in which electric utilities operate. Competition among energy producing entities, increased scrutiny from state utility boards, more restrictive operating regulations and pressure from consumers have driven utility companies from a traditional “cost plus profit” mentality into a more “dynamic market driven” reality. This new reality relies heavily on assigning tasks on a strict performance basis which has driven some traditional utility based work into various non-utility industries. Core functions such as engineering, construction, operations and testing are often being supplemented and sometimes even replaced with non-utility vendors in all facets of utility operations. This scenario is becoming more common among utilities often forcing the affected field supervision to deal with a coordination nightmare.

Many utilities commission new substation equipment and protection schemes in much the same way as they did before all the sweeping changes of the last twenty five years began to take hold. The commissioning process was often performed locally by long trusted utility employees from a variety of different departments representing the required range of disciplines. Relay technicians, for example, were usually well-seasoned and enjoyed years of training and exposure to the same basic types of electromechanical relays and protection schemes. In many cases, the design engineer was more involved with the entire construction process including the “cut in” of new equipment or devices. Local
supervision, and possibly the design engineer, knew all the employees involved and trusted their experience and judgment. Companies were smaller, more static, and possessed far more technical depth in almost all departments and/or disciplines thus facilitating success with the more local commissioning process.

The commissioning process of twenty five years ago is not an effective method of placing substation equipment and protection schemes in service today. Most utility companies are currently larger and more dynamic but employee far less people. Through the period, cost cutting efforts resulted in numerous layoffs, reduced hiring, re-training, re-deployments, and early retirement offerings that vastly depleted the work force and drastically affected the depth of knowledge they possessed. The result is that vendors are involved in most of the capital projects to some degree varying from performing a simple service to performing a complete ‘turn key’ job. Other factors also influence the commissioning practices of today such as; the introduction of an array of microprocessor based devices, more restrictive regulatory requirements and advanced outage scheduling. These factors made it essential for FirstEnergy to develop an effective commissioning process that is designed to address all the current challenges and that can quickly adapt to any new emergent issues.

BACKGROUND

FirstEnergy is an electric utility that serves more than six million customers in a 67,000 square mile area in stretching across Ohio, Pennsylvania, New Jersey, Maryland, New York, Virginia, and West Virginia. The company is based in Akron, OH and has annual revenues of about 16 Billion dollars with over 17,000 employees. FirstEnergy has over 24,000 MW of generation capacity, almost 20,000 miles of transmission lines and operates ten electric distribution utilities. The present company was formed as the result of three mergers beginning with 1997 merger between Ohio Edison and its subsidiary Pennsylvania Power with Centerior Energy to form the original FirstEnergy. In 2001, FirstEnergy merged with GPU Energy and in 2011 FirstEnergy merged with Allegheny Energy.

The rapid merging of companies within a fourteen year period has also meant the rapid integration of cultures, systems, and practices. One of the main drivers for companies to merge is to insure their survival through improved efficiency by taking advantage of the economies of scale offered by a larger combined company. Cost savings are often derived through the synergies of combining upper level management, various corporate functions, and certain central support services. Regional management, however, is far less affected since most of these activities involve the actual construction, maintenance, and operation of the electric system. Operating in this culture often means dealing with a reduced professional, support, and production staff especially when it comes to construction activities. Priority is usually given to operational and maintenance activities since they often directly affect system reliability, and therefore may require more immediate attention. It is within this environment that FirstEnergy operates, and therefore has
designed a commissioning process to ensure that all applicable standards, policies, and guidelines are met.

THE COMMISSIONING PROCESS

All new, replaced, or modified equipment and protection schemes installed in FirstEnergy substations must be properly commissioned before being placed in service. Commissioning services for equipment rated equal to, or greater than 100 kV, and the protection schemes that directly affect equipment rated equal to, or greater than 100 kV are performed by a corporate engineering department. Additionally, complete modular distribution substation configurations for all voltages (Mod Subs) are also included, since they contain a power transformer, not to mention all the elements of a complete substation in a smaller modular footprint. Mod Subs can be incorporated into an existing sub or used as a stand alone sub. Finally, all power transformers greater than 2.5 MVA and all portable substations require commissioning by the corporate engineering group.

All other commissioning services are performed locally by the appropriate regional substation services department. The regional substation services department can request commissioning by the corporate engineering department, however this corporate support is not required and is contingent on personnel availability.

Commissioning is required for each of the following circumstances:

- Installing new electrical equipment
- Installing new protection schemes
- Electrical equipment additions or replacements
- Protection scheme additions or replacements
- Electrical equipment modifications
- Protection scheme modifications
- Mod Subs (All voltages)
- Power Transformers (greater than 2.5 MVA)
- Portable Substations (all voltages)

The FirstEnergy BES (Bulk Electric System) commissioning process is administered by a corporate function named Energy Delivery Substation Maintenance (EDSM). This group is managed at the corporate headquarters in Akron, OH and has multiple subgroups that provide direct commissioning services to the local operating regions within each of the electric distribution companies. Each subgroup consists of a number of engineers (usually four to eight) that is supervised by a professional engineer who is licensed in the appropriate state(s). Those supervisors are responsible to interact with their assigned regions to provide all facets of commissioning services. In addition, the EDSM group provides several other field engineering services related to substation administration, standards, practices, construction, operation, and maintenance.
The key concept(s) in FirstEnergy’s commissioning strategy is that the commissioning engineer has complete technical authority while performing commissioning services and is held responsible that the new equipment is installed properly, fully functional and is integrated properly with the pre-existing equipment. The engineer works mainly at the job site and provides a consistent, methodical approach to the commissioning process which is essential when considering the many variables unique to each individual project. Each engineer operates within certain practical guidelines; however, it is their responsibility to make prudent technical decisions by exercising sound professional judgment. These engineers are considered practicing professionals while engaged in the commissioning process. Their authoritative technical guidance and constant on-site presence is the core of the FirstEnergy commissioning process.

**COMMISSIONING PROCEDURE**

The commissioning procedure is the general guideline that each engineer at FirstEnergy uses during the commissioning process. The procedure identifies a practical sequential approach that can be applied to every project. By following the individual steps, and applying all those which are applicable, the engineer insures that the commissioning process is always performed in a consistent and methodical manner. The steps of the commissioning procedure are as follows:

- Review print package
- Confirm R&I (Relay and Instrumentation), AC, & DC schematics
- Confirm all demolition (Demo) prints
- Identify all additions and removals
- Mark prints to reflect functional test path requirements
- Mark prints to reflect voltage confirmation test requirements
- Develop a custom Checkout Guide
- Meet with all on site employees and inform them that you are the ONLY on site authority for making any changes to the prints or relay settings
- Deliver Checkout Guide to job site and affected crews
- Confirm relay and associated CT settings
- Perform new benchmark electrical equipment testing
- Perform new CT testing
- Perform CT current pushes (must be witnessed)
- Perform functional testing on all required paths (must be witnessed)
- Confirm test switch operation via negative confirmation
- Perform voltage confirmation testing
- Re-confirm proper relay settings are in correct relays
- Determine proper switching sequences and communicate with transmission and distribution dispatching authorities (TSO/DSO)
- Review all test data, Checkout Guide steps, and switching orders
- Perform switching (must be witnessed)
- Obtain load angles as required (must be witnessed)
- Inform region of follow up requirements
• Gather, organize, and file all test data and info on job (including marked up prints) in a three ring binder or other appropriate file

PROCESS MANAGEMENT

A successful commissioning program starts with the overall supervision of the program and the full commitment of upper management. This commitment must include the alignment of all the involved entities especially local management. It also must include those groups that perform the, project management, engineering, substation services, relay and testing functions. Additionally, all services performed by outside vendors must be included in the process and managed accordingly. This program must also include any on site services provided from manufactures of equipment or systems. Many utilities contract for field service when they purchase equipment or systems that are either large, complex, or expensive. This is often done to protect the investment, educate the workforce, and ensure validation of the warranty. It is important that these manufacturers, and/or their contracted service providers, be made aware of the commissioning process and held to its adherence.

Another important aspect of a successful commissioning program is the tracking of projects and the assignment of an appropriate engineer to the project. This function is performed by the EDSM supervisor through their interaction with all the local and corporate stakeholders. The supervisor is responsible to coordinate the assignment of engineers to projects based on the work schedule and the engineering skills required on the job. This supervisor is also responsible to develop the skills of the engineers in the group through a combination of task exposures, teaming with peers, and direct mentoring. The supervisor also serves as the single point of contact for all commissioning services and in that capacity is more able to provide an immediate response to requests for any type of service.

Prior to the start of the commissioning process, the engineer may sometime be either invited (or assigned) to participate in various on site and/or pre-bid meetings. Although this is not a part of the actual process, it can be very advantageous for all those involved in the project. It gives an opportunity for all the parties to become familiar with their roles and responsibilities as they relate to job progress and commissioning the job. These meetings also provide an opportunity to establish project expectations and establish milestones. The engineer can provide information to all affected parties about required inspections, testing, and documentation.

PRINT REVIEW

Reviewing the print package is the first step performed by the engineer in the actual commissioning process. This occurs when the engineer receives the print package which should precede the start of any construction activities. No project should begin until all the entities participating in a project have received the necessary prints. At this point the
engineer examines the prints for overall applicability and accuracy. The print package generally includes the following:

- R&I Diagrams
- DC Schematics
- AC Schematics
- Wiring Diagrams (Installation & Demo)
- SCADA Diagrams (Supervisory Control and Data Acquisition)
- Ground Grid Diagrams

The wiring diagrams are not initially reviewed with the same level of detail as the other prints unless a problem warrants closer examination. During the installation process, changes are usually required with either new or existing wiring.

Once corrections are identified, they are communicated back to the engineering department or engineering service vendor. Simple corrections are made on site and the prints marked up for future updating. More serious problems may require prints to be reissued and/or may require a site visit by the engineering service provider. The commissioning engineer may reject any prints that are considered to be technically deficient.

**CHECK OUT GUIDES**

The commissioning engineer is required to prepare a unique custom made, equipment specific, "checkout guide” for each individual project. The checkout guide can only be created after the engineer receives and reviews the prints. The checkout guide is the key to a successful commissioning process. It provides information on the job milestones, required tests, specific procedures, and tasks that must be verified, witnessed, or documented by the engineer. The checkout guide assures job continuity, especially when so many different groups (both internal and external) may be involved in a single project. Once created, these guides are discussed with all affected persons associated with the project, therefore, clearly identifying specific items that must be addressed.

Usually two copies of a checkout guide are used throughout the job. One copy is left on the job site and clearly labeled as the ‘Field Copy’. All successfully completed steps identified in the checkout guide can be ‘signed off” by field personnel that have been qualified by the commissioning engineer. A second official copy of the checkout guide is kept by the commissioning engineer and clearly labeled as the ‘Master Copy’. The Master Copy must be retained with the project records. The engineer may transfer information from the Field Copy to the Master Copy as required. Often the Field Copy is also retained as a reference document.
EQUIPMENT ASSEMBLY & TESTING

The commissioning engineer is normally required to spend a large amount of time on-site during the assembly of key equipment both to ensure proper assembly and to provide consulting services. The assembly of transformers, circuit breakers, CCVTs, circuit switchers, capacitors, and disconnect switches are among the many types of equipment where assembly is closely watched. This holds especially true for transformers since both their warranty and future trouble-free operation is very dependent on proper handling during assembly. The commissioning engineer is responsible for the following tasks specifically related to transformers:

- Perform on-car transformer inspection when received
- Perform on-car accessory inspection when received
- Observe transformer assembly (dress out)
- Develop and/or confirm oil filling procedure
- Confirm operation of LTC and DETC
- Confirm operation of pumps, fans and heaters
- Confirm operation of gauges, relays, controls and alarms
- Review all acceptance testing

All devices require final acceptance testing before being placed in service. The engineer ensures that at a minimum, all testing is performed in accordance with FirstEnergy published practices. All required testing by the manufacturer is also performed to further ensure proper operation and satisfy any warranty requirements. The engineer may also give additional direction or require additional testing as warranted by his or her professional judgment.

PROTECTION SCHEMES

Ensuring the proper operation of protection schemes is one of the most important functions of the commissioning engineer. It is essential to the overall integrity of the BES that these schemes operate as designed. The engineer is responsible to identify all the protection schemes related to a project and to witness in person a functional test of every affected trip path. The engineer must also witness and confirm the operation of all affected metering, SCADA, alarms, annunciators, and local controls. The engineer is further required to witness CT current pushes and/or other methods to confirm proper CT wiring.

The evaluation of the protection scheme is performed through the functional testing of trip and close paths. This evaluation is performed using the schematic diagrams and not the wiring diagrams. This process includes verifying that the opening of test switches, or other disconnects, will properly disable the specific portion of the intended circuit, while not affecting other portions of the scheme.
Essentially, for new relay and control circuits, every portion of each circuit is required to be fully tested. When modifying existing relay and control schemes, all affected portions of the existing schemes require testing. Although retesting all portions of the relay and control scheme regardless of whether they were disturbed is preferred, this is not always possible. For example, fully testing a new trip initiate contact from a breaker failure relay into an in-service bus differential scheme (with plans to trip all breakers) may not be possible due to outage constraints. Accordingly, the full relay and control scheme can not be tested, however it is essential that all portions of the scheme that may have been impacted by the new wiring changes are checked to ensure that the full functionality of the existing scheme remains.

When deciding how much of the existing scheme to functionally test, the commissioning engineer is aided in the task of evaluating protection schemes through the application of an analysis technique called “Disturbed Node Functional Testing” (DNFT). This analysis method and testing process applies to any modifications made to various types of existing wired schemes and is performed using the DC schematic diagrams. The process is summarized below:

<table>
<thead>
<tr>
<th>Disturbed Node Functional Testing (DNFT)</th>
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<td>When a wire or component is added to, or subtracted from, a trip, close, alarm, control or indication path than the electrical nodes to which they are connected are considered “disturbed” and must be identified (highlighted). As a minimum, every one of the aforementioned AC or DC current paths connected to those nodes shall be confirmed through functional testing.</td>
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The application of the DNFT technique is designed to identify both engineering and wiring errors and minimize the risk of future misoperations. This is especially helpful when the additions and removals on a schematic diagram do not adequately reflect the actual complexity of the wiring changes. An application of this technique is shown in the example below (capital replacement of a breaker) which necessitated the change of a ‘52a’ contact in an otherwise undisturbed relay scheme. Figure 1 shows the DC schematic diagram with the contact identified. Figure 2 shows all the portion of the circuit (highlighted in yellow) that must be tested, as a minimum, as a result of disturbing the two nodes connected to the new ‘52a’ contact. Finally, Figure 3 shows two examples of possible circuit paths to be checked for functionality to ensure that portions of the affected node remain intact following the replacement of the 52a contact in this circuit. The orange/yellow highlighted leg of the Figure 3 schematic illustrates a check through of the Zone 2 line relaying to ensure that portion of the coverall scheme remains intact and functional. Similarly, the blue/yellow highlighted leg of the Figure 3 schematic checks the continuity and functionality of the ground relaying. Further checks through each yellow highlighted portion of the circuit must be conducted until they are all tested and verified.
Adding an ‘a’ contact to an existing relay scheme.

Figure 1

Affected nodes are highlighted.

Figure 2
Examples of two paths chosen to prove functionality.  
Figure 3

In addition to the normal functional testing, or the application of the DNFT technique for equipment modifications, end-to-end testing may also be required. End-to-end testing is a required commissioning test for PJM member companies on all interconnected transmission lines for PJM member companies that utilize communication assisted protection schemes. FirstEnergy requires end-to-end testing to be performed as a part of the commissioning process on all 230 kV and greater transmission lines with communication assisted protection schemes. The commissioning engineer is required to be on-site during end-to-end testing and is responsible for providing technical guidance and testing oversight.

SWITCHING & ENERGIZING

The commissioning engineer plays a key role during the switching process. The engineer provides guidance required for the creation of switching orders to the appropriate system operations department. Once the orders are created, the engineer reviews them and any required corrections are made. Prior to the day of switching, the engineer will generally conduct a full walk down of the entire project. This includes stepping through the entire switching order with the assigned crew. During this time, the labels on all devices identified in the switching order are confirmed and switches and breakers are placed in the appropriate starting open or close position.

Switching orders used for commissioning new or modified equipment must include two important steps, each of which requires the commissioning engineer to be on-site and fully engaged in the process. For each new piece of equipment, a step is created where the commissioning engineer must “release for test”. This step allows the equipment to be energized and testing or analysis to be performed. This includes obtaining and/or verifying certain voltage and current information from various devices or possibly
adjusting relay settings. Once the switching is completed and the equipment is deemed satisfactory for normal service by the commissioning engineer, a “release for service” step is performed. Once this step is completed, that piece of equipment or protection scheme is officially turned over to the system operator as ready for normal service.

Energizing new equipment is a key consideration when creating switching orders. The engineer will generally require all new equipment (which means anything new that will be energized at primary voltage) to be picked up with a dedicated circuit breaker with already proven relay protection. Energizing new equipment with any type of switch or circuit switcher is avoided. The energizing of new equipment is performed through a device that can clear a bolted three phase ground or phase–to-phase fault. When a circuit breaker is unavailable at the sub where the work was performed, then a breaker at a remote sub is chosen and appropriate switching occurs to properly isolate the system.

The commissioning engineer’s role is never more important than on the actual day of switching. The engineer is the technical leader on-site and provides all the direction relative to the switching process. Recognition of this single point of authority (unique to switching associated with commissioning) provides a safer general environment during switching. Switching always begins with a safety and technical briefing led by the engineer. This includes one last look at the equipment to be energized to ensure that the area is clear and all grounds have been removed. Once the site is cleared, the engineer initiates the start of the switching sequence while retaining the full authority to pause or delay the process to perform testing or other necessary tasks. The switching process continues through the, “release for test” and “release for service” steps. Final load angles (current and voltage phasor measurements at all relay and metering points) are taken and evaluated for the record when switching is completed.

DOCUMENTATION

The commissioning engineer gathers all equipment test reports, relay settings, correspondences, notes, the checkout guide, and any other pertinent information regarding the project. This information is retained by the commissioning engineer in a three ring binder or other appropriate filing tool for future reference. This referenced information may become important in the event of future investigations or inquiries. In addition, retained documents such as the checkout guide can be used as reference material for future projects.

FEEDBACK & PRINT MODIFICATIONS

It is important to have a means to provide feedback to the various groups involved in the commissioning process. This feedback is usually communicated to all responsible parties at a monthly project meeting through the supervisor of the commissioning engineers. In addition, immediate important feedback is provided directly to any department or individuals as required. The commissioning engineer also reviews the marked up prints
for accuracy. The local substation group returns a copy of the marked up prints to the engineering department so that accurate updated prints can be created and issued.

In addition, the commissioning engineers communicate among themselves on a local (regional) level on a regular basis. The commissioning engineers also meet locally once a quarter for staff meeting where less formal technical presentations are made and safety issues are discussed. Once or twice a year, all the FirstEnergy commissioning engineers meet at a two day technical event. The meeting involves more formal presentations related to technical issues, safety information, and general corporate information. The meeting on a whole provides the entire FirstEnergy staff of commissioning engineers an opportunity to meet one another and it provides a forum for the exchange of practical technical information.

DESIGNING A COMMISSIONING PROCESS

Designing a commissioning process is not that much of a challenge when you consider that every utility in the United States probably already has one. As an industry, we have been installing new equipment for well over a hundred years. And in most cases, the methods and procedures that are practiced have been successful enough. Unless you have felt a “bump in the road” as a result of an audit, fine, FERC or NERC investigation or state utility commission order, there probably isn’t a lot of motivation to change what is already in place. However, for those utilities that have felt that bump, or have changed through attrition, mergers, downsizing, enhanced retirements, budget cutbacks, asset sales, or just following the advice of consultants, there is a need to design a commissioning process that is effective in the current environment, and can remain effective in any future environment.

An effective commissioning process can only be designed when an honest assessment is made of the realities being experienced at the job site. Once these realities are identified only then can realistic goals involving a commissioning process be developed. The most important goal must be the safety of all those involved followed by insuring the overall integrity of the BES or distribution system. An effective commissioning process must have the following key attributes:

- A foundation in safety
- A well trained professional staff
- A committed corporate and local management
- An engaged workforce
- A focus on insuring system (BES) integrity
CONCLUSION

Establishing an effective commissioning process will ensure that projects involving substation construction, assembly, and installation will meet all company standards and that newly installed or modified equipment will function correctly when placed in service. In today’s environment, it is more important than ever to have a dedicated and precise method to address the many variables associated with the commissioning of new substation equipment and protection schemes. Regulatory pressure alone is sufficient motivation to make designing an effective commissioning process a priority.

Designing an effective commissioning program requires an honest assessment of both the current environment and the available resources. The program must also be managed by competent individuals surrounded by a staff of well trained engineers. These engineers will be most effective when they are endowed with full technical authority for commissioning assigned projects. Their constant on-site presence and technical leadership is paramount to the success of any commissioning program.

ACKNOWLEDGEMENTS

The author would like to acknowledge Eric Schock, General Supervisor at FirstEnergy Corp. for his development and implementation of the Disturbed Node Functional Testing (DNFT) method.

BIOGRAPHY

Lawrence P. Hayes is a Supervisor in the Substation Maintenance department at FirstEnergy Corp. in Farmingdale, NJ. Larry has over 27 years of direct field experience in the construction, operation, maintenance, and protection of substation electrical equipment. Larry has held numerous engineering and management positions in the FirstEnergy family of companies. Larry currently serves as the chairman of the PJM Relay Testing Subcommittee (RTS) where he represents FirstEnergy. Larry is also the co-founder, and VP of Compliance & Engineering, of E-Waste Experts, Inc., which is an electronic waste processing company in Pennsylvania. Larry has a BSEE from Drexel University in Philadelphia, PA and he is a registered Professional Engineer in both New Jersey and Pennsylvania.