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Best Practices and Economic Benefits of Commissioning, Load Testing, and Facility Optimization

Mark Siira
Director of Business Development andTechnology Strategy

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Executive Summary

Overview

This document is a guide for Facility Managers who are interested in maximizing reliability, availability, and efficiency of the primary and backup power supply systems at mission critical facilities. The best practices described in this paper will lead to optimized facility systems, increased energy efficiency and improved reliability and availability.

System testing is commonly undertaken at different levels during the commissioning of a facility depending on the critical nature of the equipment installed and the effect of downtime on the facility owner's business. Additionally, testing is done on a recurring basis depending on the maintenance guidelines set by company policies, specific industries or regulatory agencies. Finally, testing is often done to validate corrective actions resulting from a facility power system failure or downtime of the facility owner's business.

After many years of experience in commissioning and load testing generators, best practices can be obtained by using experienced professionals to design the test, integrate testing into the building project plan, test all of the subsystems that will affect the performance of the electric power system, and use innovations in load testing that produce actionable information and confidence in the validation as it is obtained.

In an attempt to improve readability, much of the technical detail and references are included in an appendix. Also included in the appendix are references and checklists that should simplify the choices managers have to make relative to commissioning.

Best Practices and Innovations in Load Testing

This paper identifies the following best practices, which are elaborated on more completely in clause 5:

Planning

The commissioning process takes place in all phases of a project and should be planned as early as possible in the project.

- A clear definition of roles and responsibilities should be set before the project starts and refined at each phase of the project. All stakeholders should be involved in planning including: owner's facility management team, commissioning agent, equipment manufacturer, general contractor, and electrical contractor.
- Implement elements of the commissioning plan at each phase of a project.
- Contingency plans should be included for project special circumstances that could affect timing of the commissioning.
- Implement a commissioning (program that includes artificial load simulations) as a part of ongoing facility maintenance.

Technology Innovation

Technology that enables efficiency in the commissioning process can accelerate the commissioning schedule and reduce total cost.

- Specialty load banks, cables, switchgear and controls can be temporarily brought in for a test and greatly reduce setup time, improve safety and operating efficiency of the facility.
- Implement a load bank test plan that accurately simulates the electrical and thermal load characteristics of the equipment to be used in the data center. This will prevent oversizing the cooling system and result in optimized efficiency and lower maintenance costs.
- It is more realistic to test medium voltage generators with MV load banks which require 15x fewer cables and 5x less time to set up and tear down.
- Integrated power quality monitors complete more tests in less time, collect more data, and reduce report generation time. Integrated monitoring replaces separate devices that are commonly used independently such as Fluke power quality monitor, the Astro-Med, and a Harmonic Logger. (http://www.comrent.com/Solutions/power-quality-monitoring-and-reporting.html)
- Bus Track Adapters for data centers overhead bus results in fast setup and shorter cable requirements.
- Control communications integrated into a load bank fully integrates all load bank functions, controls, and operations so that the load bank can be operated remotely from the Network Operations Center. All data is collected and integrated directly into the SCADA System.

An experienced professional services firm like ComRent that has the latest load bank technology and repeatedly runs load tests offers many advantages in terms of reliability, cost, and safety. ComRent can shorten the elapsed time of the load test by reliably bringing the appropriate equipment with the shortest lead time. Most of all, using the latest load bank technology will reduce overall commissioning costs.

1. Trends that Drive the Increasing Importance of Load Testing

Although the frequency and breadth of load testing upon the commissioning of a building has increased in the last 15 years, there are several trends that are driving this to an increased level of importance.

Changing Interconnection Standards

Interconnection standards for connecting a local electric power system to the electric grid were developed in the late 1990s through the collaboration of electric utilities industrial facility owners, regulators, and technical consultants. The passage of IEEE 1547 – "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems" – leveled the playing field and gave a clear path to what was needed to increase the reliability and availability of the local power system by enabling synchronization with the grid and multiple connections from the utilities' distribution or transmission system. Simply put, the standard required that Distributed Energy Resources (DER) cannot affect the voltage, frequency or power quality of the electric power system (EPS)

In late 2015, standards-making organizations collaborated once again on a revision of this standard, which allows voltage regulation and frequency regulation at the point of common connection (PCC). Additionally, it is being considered to include voltage and frequency ride-through requirements, updated Flicker requirements and updated harmonic levels.

There is a significant change in the typical system topologies that were used in the past. These topologies will increase again the complexity of power systems and critical facilities, but also drive added revenue streams from the exchange of ancillary services such as power factor correction, voltage regulation, and frequency regulation

These trends will have significant impact on the importance of load testing in the coming years.

Micro-Grids and Complex Systems

Micro-grids are being used as a solution in areas where power quality and reliability is low, such as in remote areas and in campus settings. Although a common terminology that describes micro-grid operations still has not emerged, it is generally viewed as the viable way to increase the penetration of renewable energy in an electric power system. Additionally, the concept of a micro-grid allows for expansion and modification over time as needs change. The obvious complexity and interaction of multiple loads and sources will drive the increased importance of load testing in the actual environment.

Interoperability of Software and Communication

With the EPS, a roadmap and guideline to achieving the “smart grid" was enacted in 2009, which was validated as consensus in 2011. A collaborative effort from electric utilities, standards making organizations, and industry produced a guide for interoperability of the electric power system with communication technology and information technology (IEEE 2030 - 2011). This guide mapped the communication protocols and data flows required to perform the functions on the grid and within the customer’s facility. Over time, this interoperability will result in more common approaches to monitoring and control and information exchange related to the electric power system. This may likely drive opportunities for upgrading systems to keep communications capabilities up to date to participate in market activities.

Integration of Renewables and Electric Vehicle Infrastructure

There has long been a desire to integrate renewable energy sources into the electric power system. Many attempts have been made to integrate through distributed energy sources located at customer facilities. However, the high cost of historical approaches has limited the adoption of this application. In light of the trends discussed above, the power industry can expect the emergence of more creative and cost-effective ways to integrate renewable energy sources into electric power. As noted above, also, retrofit and upgrade opportunities will drive an increasing need to do more load testing.

2. Three Types of Load Testing

There are three types of load testing commonly performed on facilities; Commissioning Tests, Maintenance Testing, and Corrective Action Validation Testing. The material presented at PowerGen 2015 will focus on the commissioning tests. Materials on the other two categories are included in this manuscript for completeness.

A. Commissioning Testing

The purpose of commissioning is to provide documented confirmation that the building systems function in compliance with the criteria set forth in the project documents to satisfy the owner's operational needs. (Source: Building Commissioning Association; www.bcxa.org). The level and complexity of the commissioning depends on many factors, including project schedule, cost and risk/benefit, uptime goals for the facility, and most importantly business drivers such as energy savings, LEED sustainable design, and regulatory issues ((HIPPA, JCAHO, Sarbanes Oxley). The levels of testing are commonly described at five different levels. Level I would be a factory acceptance testing of the subsystems; Level II would be a site arrival inspection of the component systems; Level III is startup acceptance testing; Level IV would be functional performance testing; and Level V would be an integrated systems test. Most of the comments discussed in this document deal with Level IV and Level V commissioning tests.

Commissioning Process

Through extensive experience and evaluation of different applications of commissioning, ComRent has identified recommended best practices in the process.
Generally, it is important to note that the commissioning process takes place in all phases of a project. Additionally, it is important that there be clear definition of roles and responsibilities before the project starts and refined at each phase of the project. Finally, Contingency plans should be included for project special circumstances that could affect timing of the commissioning.

Building construction or utility projects can be generally summarized in 5 phases. The recommended best practices are listed after each phase description.

Phase	Description	Best Practices
Project Planning	Pre-project development activities ensure that your commissioning plan and budget are included in the project development estimates along with organizational responsibilities. Agreements in place	• Develop commissioning plan with budget • Ensure the plan comprehends Utility Commissioning Requirements

		• Clarify roles and responsibilities for each phase • Develop a commissioning checklist for the project
Project Design	During the design phase, ensure that the elements of the commissioning plan are included in the project and that design requirements specific to this project are included in the commissioning plan.	• Develop a written commissioning plan, including utility and supplier test requirements • All parties involved should sign off on the commissioning plan prior to construction
Project construction	During this phase, the equipment is installed and if required, the type test and approvals should be verified. Project schedule should be integrated and focused on timing for the final commissioning date.	• Factory acceptance testing is performed on critical subsystems such as disconnect device, inverter, HVAC • Avoid duplication of tests (Suppliers performing design verification tests) o Making this a witnessed test may simplify plans • A system test should be performed at the subsystem level during the commissioning process.
Acceptance	The commissioning test is conducted once all equipment is installed as well as when the system goes live to verify correct operation. The system should then be tested to ensure compliance with IEEE 1547.1a (IEEE Standard Conformance Test Procedures) and IEEE 1547.1 Revision (2018).	• Most systems require disconnect tests • May be required to validate performance for reactive power and V and F ride through • Testing of communication systems should be performed • Acceptance testing can be completed under special circumstances that can affect timing; for example, when a substation is not energized or the utility wants to verify

		system protection behavior before connecting.
Handoff to operation	The requirements included in the commissioning test should flow into the maintenance plans that are put in place for the power system.	• The test data from the commissioning test can be used as a baseline for future testing of the system. ▪ There should be a mechanism identified to identify and resolve post-commissioning issues.

Commissioning Test Design and Program Goals

Commissioning testing may be performed in the following areas:

- **Power quality –** Testing for the presence of harmonics, voltage, or frequency abnormalities. These tests are important in facilities that integrate UPS systems. They will also become more important as renewable energy sources such as photovoltaic, wind, and energy storage are integrated into distributed power systems. Additionally, testing these attributes will increase in importance as interconnection standards begin to allow for voltage regulation, frequency regulation, and power factor correction at the point of common coupling (PCC).
- **Backup power/grid interconnection –** Testing of the emergency backup generators, automatic transfer switches, and paralleling switchgear to ensure that the system meet required codes and standards, and perform in accordance with the electric power provider.
- **Critical facility systems integration –** Tests on highly complex facilities, such as data center testing can be performed using specialized load testing equipment that reduces the setup time for the test and provides a more realistic simulation of the facility operation.

Commissioning Testing for New Buildings

Commissioning new buildings relies heavily on the commissioning agent for that facility.   Here are some typical things to consider:

Commissioning Specifications:

Best practitioners develop commissioning specifications to ensure that commissioning requirements are included in the construction documents. These should describe all contractor-related commissioning responsibilities. For clarity and information, list the commissioning agent and other non-contractor team member responsibilities (construction manager, owner, design team). Clearly delineate between the contractor’s responsibilities and the responsibilities of the rest of the team.

Commissioning Requirements Definition:

Requirements should be included for:

- Submittals
- Commissioning Meetings
- Commissioning schedule
- Construction checklist development and execution
- Functional test procedure format and development
- Startup process
- Measuring instrument calibration requirements
- Test readiness confirmation
- Functional testing process - including management, execution and documentation
- Balancing report review and reading validation
- Issues log process
- Deferred functional testing
- Training verification
- Certifications required of personnel
- O&M manuals
- System Manual requirements

Functional Testing

Another best practice is to have a functional testing scope for each piece of equipment or type of assembly or system. Manufacturer's specifications, operating manuals, or installation criteria provide guidance regarding proper startup and initial run out criteria. These list the modes to be tested, under what conditions and give the acceptance criteria.

Identify what kind of testing is and is not part of the formal commissioning process.

Delineate between commissioning functional testing and contractor quality control and other testing (e.g., duct and pipe pressure testing, etc.). The test reporting format should be specified and agreed upon prior to commissioning by the contractor or commissioning agent.

When functional commissioning testing is complete on each critical asset, the system should be functionally checked to meet design criteria. Many times, individual equipment commissioning will not identify the operational issues that will only exhibit when a facility power system is validated holistically. Again, reporting format and criteria must be defined and agreed to with the contractor or commissioning agent responsible for the system check. This will ensure that a proper system of accountability is in place for both individual system components and onsite as-built performance.

Commissioning Testing for Existing Buildings

The majority of existing buildings have not undergone any type of commissioning or quality assurance process. Additionally, over time the facility requirements change and the operational efficiencies of buildings tend to degrade. Because of these factors, many buildings are performing well below their potential, use more energy than necessary, and cost more to operate than they should. The commissioning agent responds to an owner's desire to improve building performance, solve comfort and operational problems, and reduce operating costs. Best practices for commissioning existing buildings include:

- Verify that a facility and its systems meet the Customer Functional Requirement (CFR)
- Improve building performance by saving energy and reducing operational costs
- Identify and resolve building system operation, control and maintenance problems
- Reduce or eliminate occupant complaints and increase tenant satisfaction –
- Improve indoor environmental comfort and quality and reduce associated liability
- Document system operation - Identify the Operations & Maintenance (O&M) personnel training needs and provide such training –
- Minimize operational risk and increase asset value
- Extend equipment lifecycle
- Ensure the persistence of improvements over the building's life
- Assist in achieving LEED for Existing Buildings (http://www.usgbc.org/LEED) –
- Improve the building's ENERGY STAR rating (http://www.energystar.gov/)

Guidelines for Building Commissioning

Building commissioning today is a "whole-building" or "total building" process in which building systems and their interactions are tested and verified to suit current requirements. This integrated approach maximizes positive results and helps to ensure that the building is operated safely, efficiently, and meets the CFR. Although limiting the commissioning scope to focus on a single system (i.e. HVAC systems) or singular objective/goal (i.e. save energy) is a typical practice in the industry, this narrowing of scope is not likely to produce a building that operates best overall. The objectives of a commissioning Planning Phase are to develop/confirm the owner's needs and requirements for the facility, document them through the development of a CFR document, and to develop a commissioning Plan to define the commissioning process for the facility.

Investigation Phase

The objective of the Investigation Phase is to conduct the site investigation to compare the actual building conditions and system performance with the owner's current operational needs and requirements defined by the CFR. This phase concludes with the completion and review of a master list of findings that identifies facility improvement measures or corrective actions that will improve building and system performance to meet the CFR, reduce energy and O&M costs, and/or improve the indoor environmental quality. Included in this phase is the development of the test procedures for the systems identified in the project scope. Test plans typically focus on confirming that the system performance is meeting the performance requirements of the owner set forth in the CFR.

System Testing

During this phase, Commissioning agents perform system testing to evaluate the performance of building systems. In addition, any anomalies or issues identified in the earlier Investigation Phase steps should be considered for further evaluation during system testing to determine root causes and possible solutions. It is recommended that the testing process include the verification and calibration of critical sensors. Typically, critical sensors are those sensors which are essential to the effective and efficient operation of the building systems. If appropriate and agreed upon by the commissioning team, perform simple repairs or containment or containment actions

Performance Assurance

Commissioning agents will evaluate methods of measuring system performance and verifying proper implementation to demonstrate the success of the FIMs implemented. Each measure should have a verification methodology appropriate to the size and complexity of the measure. The identified verification methodology is then incorporated into a Measurement and Verification (M&V) Plan. The M&V plan is intended to provide a comprehensive protocol to verify the performance of the measure/system and confirm that the predicted energy savings have been achieved upon the completion of implementation.

Establish a Plan

Next, a plan is developed for operational sustainability and ongoing commissioning to ensure the consistency of results and continuous improvement. This should be a key deliverable of the Turnover Phase. The plan will provide the building personnel with detailed instructions, systems, and tools for strategic operational, monitoring, and maintenance tasks that help maintain the commissioning process performance benefits and support continuous improvement.

Document Changes

An operator's log is required to establish a baseline and keep a record of significant events such as equipment replacement, maintenance or testing, and problems and their resolution. If possible, the log should be kept electronically to allow for easy searching. CMMS (Computerized Maintenance Management System) software is commercially available to aid in this documentation and can be used as an asset maintenance scheduling and record system. More details on the Commissioning Testing Checklist can be found in Appendix E.

B. Maintenance Testing

Maintenance tests are performed on regular intervals as determined by the facility owner's policies, the industry's recommended practices, and the regulatory agencies requirements. As a general rule, recurring testing comparable to commissioning tests can be performed on an annual basis and serves the purpose to ensure that all of the subsystems in a complex facility are operating as intended by the designers.

Recurring Maintenance Testing

The U.S. Navy pioneered preventive maintenance as a means to increase the reliability of their vessels. By simply expending the necessary resources to conduct maintenance activities intended by the equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved over that of a program just using reactive maintenance. Studies indicate that using a recurring testing approach can reduce equipment life costs by as much as 12% to 18%.

Benefits of a proactive recurring maintenance testing on the electric power system include:

- Cost effective in many capital-intensive processes
- Flexibility allows for the adjustment of maintenance periodicity
- Increased component life cycle
- Energy savings
- Reduced equipment or process failure

- Increased component operational life/availability
- Allows for preemptive corrective actions
- Decrease in equipment or process downtime
- Decrease in costs for parts and labor

Recurring maintenance includes not only preventive maintenance, but enhances the concept to include predictive maintenance. This differs from preventive maintenance by basing maintenance requirements on the actual condition of the machine rather than on some preset schedule. The fundamental difference between predictive maintenance and preventive maintenance is that predictive maintenance is used to define the required maintenance task based on the quantified material/equipment condition.

Predictive Maintenance Testing

There are many advantages of predictive maintenance. A well-orchestrated predictive maintenance program will all but eliminate catastrophic equipment failures. It is possible to schedule maintenance activities to minimize or delete overtime cost, and to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs. The operation of equipment can be optimized, saving energy cost and increasing plant reliability. Past studies have estimated that a properly functioning predictive maintenance program can provide a savings of 8% to 12% over a program utilizing preventive maintenance alone. Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30% to 40%. In fact, independent surveys indicate the following industrial average savings resulting from initiation of a functional predictive maintenance program:

- Return on investment: 10 times
- Reduction in maintenance costs: 25% to 30%
- Elimination of breakdowns: 70% to 75%

Reliability Centered Maintenance Testing

There are number of traditional philosophical approaches to electrical maintenance, such as run-to-failure (RTF), maintain as necessary, and perform maintenance on fixed time schedules, and predictive maintenance, which are briefly summarized in the following sections. The reliability-centered maintenance (RCM) program is gaining favor because it combines the strengths of reactive, preventive, predictive, and proactive maintenance strategies. The RCM approach to electrical equipment is discussed in a greater detail than other maintenance strategies because it is becoming a maintenance program of choice. However, most power utilities, manufacturing firms, and owners of plant facilities utilize a combination

of these programs.

Which Maintenance Approach to Adopt?

The decision as to which approach to adopt is largely dependent on the scope of systems and equipment, as well as a function of how management views the cost and benefits of maintenance. Predictive maintenance (PM) or condition monitoring uses nonintrusive testing techniques, visual inspection, performance data, and data analysis to assess equipment condition. It replaces arbitrarily scheduled maintenance tasks with maintenance tasks that are driven by the item's condition. Trending analysis of data is used for planning and establishing schedules. Since the technology is not applicable to all types of equipment for possible failure modes, it should not be the sole maintenance strategy employed. It is most effective when used in conjunction with a preventive program.

The optimum PM approach for any specific plant, system, and/or piece of equipment depends on a variety of factors, including the following:

- Safety impact of equipment failure
- Productivity and profitability impact of equipment failure (including costs of lost production as well as failed equipment repair or replacement)
- Cost of PM
- Failure rate and/or anticipated life of equipment
- Predictability of failure (either from accumulated operating time or cycles or from discernible clues to impending failure)
- Likelihood of inducing equipment damage or system problems during maintenance and testing
- Technical sophistication of the plant maintenance staff
- Availability of equipment reliability data to support RCM

The ideal maintenance program is reliability-based, unique to each plant and to each piece of equipment. In the absence of this information I suggest the following time-based maintenance schedule and matrix. (See Table 2-4)

Although not listed as a separate category, full load testing can be implemented to achieve the most comprehensive results and replace multiple electrical tests by duplicating the functionality in the operating environment it will be used. The following load testing innovations are available today to ensure successful full load testing:

Specialty Load Banks, including

- Rack mounted load banks
- Networked controls for rack-mounted load banks
- Liquid cooled load banks
- Load banks with advanced communication to building management system
- Power Quality Testing – Integrated power quality testing with expert analysis and reporting

C. Corrective Action Validation Testing

Frequently, full load testing is performed to validate that a corrective action was implemented as a result of a failure in the system's performance or to correctly adjust the system's performance to the intended levels. An example of this would be disruption of downstream and upstream systems caused by harmonics generated by power electronics in the UPS. Innovative technology exists to incorporate power quality testing as a part of a normal load testing routine.

As business operations become more process oriented and aligned with ISO 9000 quality systems, an organization needs to apply suitable methods for monitoring and measurement of mission critical systems. As this relates to critical electric power systems, failures of the system or sub systems need to have the corrective action validated. This validation not only should prove that the system is operating as intended, but also should include an overall system test to identify any impacts on other system components.

A very effective discipline for managing and validating corrective actions in processes or operations, commonly used in the North American Automotive industry is the Eight Disciplines or 8D. 8D also refers to the form that is used to document the problem and resolution. It is also called an 8-D Report or Corrective Action Report. 8D is a structured approach to solving problems that emphasizes data collection and analysis. Additionally, it requires an organization to test progress and results, namely verify and validate that the corrective action is working. Analysis and results are documented in an information database that allows the organization to anticipate future problems and prevent recurrence. The 8D process has been incorporated into the Six Sigma methodology as DMIAC, a five-step approach with the sole objective to drive costly variation from manufacturing and business processes. The five steps in DMAIC are:

- Define
- Measure
- Analyze
- Improve
- Control

As the backbone of the Six Sigma, DMAIC delivers sustained defect-free performance and highly competitive quality costs over the long run Additional information on this and other structured problem solving methods including the 8 Disciplines or 8D can be found in Appendix B

3. The Benefits of Functional Load Testing for a Power System

Reliability and Availability

Load testing of a facility at commissioning ensures that the system performs its intended function as expressed by the facility designers in the project documents. A comprehensive test not only provides information about the performance of components or subsystems (generators, UPS, power distribution units), but also gives information about the operation of the overall system in the environment in which it is expected to perform. This process often leads to identifying technical problems and allowing solutions to be implemented before a facility is operational. Complex systems such as a facility's electric power mains supply, emergency backup, uninterruptible power supply, and power distribution need to be tested and the functional performance validated to ensure the intended availability and reliability set forth by the designers.

Economic Benefits

There are three types of economic benefits that can be derived from a well- executed load testing plan. First, the capital cost of the project can be reduced by lowering the labor required to perform the test as well as identifying corrective actions and investment before the facility is operational. Second, load testing can reduce the risk of operational failures in the facility. This enables the business using the facility to operate effectively and achieve the desired levels of facility reliability and availability. Third, comprehensive load testing will reduce the incidence of random failures that can be commonly seen in complex systems across the system's lifecycle. The system is made up of a large number of subsystems, each of which continually update firmware, software, and control logic. Over time, the calibration of these subsystems may need to be tweaked to ensure that control logic, timing, and functional operation continue to perform as expected.

A primary focus of a facility manager is to Reduce Risk for the business by providing electric power at a high level of availability. Availability is the percentage of time that a system is available to perform its function(s), this variable has been the focus for all operators of critical electric power systems. Table 1 highlights a trend towards increasing availability. In the 1990s, the standard for availability was "five nines", or three minutes of downtime per year. The current expectation is "seven nines", or three seconds of downtime per year.

TABLE 1

	Availability	Hours of Downtime* (*Based on a year of 8760 hours)
Critical Facility Expectations	0.9	876
	0.999	8.76
1990's	0.99999	0.0876
Current	0.9999999	0.000876

Correlation between Maintenance, Testing and Failures

The reliability of electrical equipment used in utility and industrial applications has been the result of an extensive survey conducted by IEEE. Each participant in the survey was asked to give his or her opinion of the maintenance quality in the facility. A major portion of the electrical equipment covered in the survey had a maintenance quality that was classed as "excellent" or "fair." The maintenance quality had a significant effect on the percentage of all failures blamed on "inadequate maintenance."

As shown in the following in Table 2; of the 1469 failures reported from all causes, inadequate maintenance was blamed for 240, or 16.4% of all the failures.

TABLE 2: Summary of Survey Conducted by the IEEE Industrial and Commercial Power Systems Committee

Maintenance quality	Number of Failures		Failures due to inadequate maintenance
	All causes	Inadequate maintenance	
Excellent	311	36	11.6
Fair	853	154	18.1
Poor	67	22	32.8
Total	1469	240	16.3

One takeaway from this analysis that can lead to best practice by system operators is to use Published material as reference in planning inspection and maintenance practices. The available material can include:

- IEEE Gold Book - Design of Reliable Industrial and Commercial Power Systems
- Utility practice of system coordination studies (IEEE 1547.7)
- NFPA® 70B, Recommended Practice for Electrical Equipment Maintenance. Provides specific information on how to set up a maintenance program.
- ANSI/NETA Standard For Maintenance Testing Specifications for Electrical Power Equipment and Systems

4. Conclusion

An Emergency Power System is an interconnected system that has component systems containing multiple sub-systems that must work in concert to achieve the fire protection and life safety goals intended. These interconnections need to be tested for proper operation in addition to the acceptance testing of the individual components. An integrated testing plan – including commissioning testing, maintenance testing, and correction validation testing – using load banks will confirm that the building systems function as the registered design professional has intended.

5. Best Practices and Innovations in Load Testing

Although there are similarities among the three approaches to load testing, the application of recent innovations can provide unique benefits to an organization that needs to test an electric power system and ensure its long-term availability As such, ComRent recommends the following best practices:

Planning

- Commissioning should be planned as early as possible in the project.
- All stakeholders should be involved in planning owner's facility management team, commissioning agent, equipment manufacturer, general contractor, electrical contractor.
- A well-planned test executed by experienced, trained personnel can reduce project lead time, expense and improve the appearance of the site.
- Include a load bank plan during project design Commissioning is a component of the project lifecycle.
- Implement a commissioning (program that includes artificial load simulations) as a part of ongoing facility maintenance.

Implement elements of the commissioning plan at each phase of a project

The following summarizes best practices in each project phase:

Project Planning Phase (Pre-Bid)

Pre-project development activities ensure that your commissioning plan and budget are included in the project development estimates along with organizational responsibilities. Agreements in place

- Develop commissioning plan with budget
- Ensure the plan comprehends Utility Commissioning Requirements
- Clarify roles and responsibilities for each phase
- Develop a commissioning checklist for the project

Project Design Phase

During the design phase, ensure that the elements of the commissioning plan are included in the project and that design requirements specific to this project are included in the commissioning plan.

- Develop a written commissioning plan, including utility and supplier test requirements
- All parties involved should sign off on the commissioning plan prior to construction

Project construction Phase

During this phase, the equipment is installed and if required, the type test and approvals should be verified. Project schedule should be integrated and focused on timing for the final commissioning date.

- Factory acceptance testing is performed on critical subsystems such as disconnect device, inverter, HVAC
- Avoid duplication of tests (Suppliers performing design verification tests)
- A system test should be performed at the subsystem level during the commissioning process.

Acceptance Phase

The commissioning test is conducted once all equipment is installed as well as when the system goes live to verify correct operation.

- Testing of communication systems should be performed
- Acceptance testing can be completed under special circumstances that can affect timing; for example, when a substation is not energized or the utility wants to verify system protection behavior before connecting

System handoff to operation

The requirements included in the commissioning test should flow into the maintenance plans that are put in place for the power system.

- The test data from the commissioning test can be used as a baseline for future testing of the system.
- There should be a mechanism identified to identify and resolve post-commissioning issues

Technology Innovation

- Technology can accelerate the commissioning schedule and reduce total cost.
- Specialty load banks, cables, switchgear and controls can be temporarily brought in for a test and greatly reduce setup time, improve safety and operating efficiency of the facility.
- It is recommended to implement a load bank test plan that accurately simulates the electrical and thermal load characteristics of the equipment to be used in the data center. This will result in optimized efficiency and lower maintenance costs.
- It is more realistic to test medium voltage generators with MV load banks which require 15x Fewer Cables and 5x less time to set up and tear down.
- Use remotely controlled load banks to reduce time and associated man hours to complete tests. Wireless communication and control capability are available although not yet in common use.

- Integrated power quality monitors complete more tests in less time, collect more data, and reduce report generation time. Integrated monitoring replaces separate devices that are commonly used independently such as Fluke power quality monitor, the Astro-Med, and a Harmonic Logger.
  (www.ComRent.com/cx-monitor
- Adaptive controls can interact with subsystem controllers (generator control or building management system) to autonomously react to problematic conditions.
- Bus Track Adapters for data centers overhead bus results in fast setup and shorter cable requirements.
- Liquid cooled load banks allow for high electrical and thermal load density to be put into the final environment and allow for a smaller footprint, if needed, if they must be positioned in tight spaces. (www.experiumtech.com/EXLS 250KW 480V Water-Cooled Resistive Load Bank
- Control communications integrated into a load bank fully integrates all load bank functions, controls, operations so that the load bank can be operated remotely from the Network Operations Center. All data is collected and integrated directly into the SCADA System.
- Adaptive control can be implemented to allow the load to be varied depending on operating conditions.

An experienced professional services firm like ComRent that has the latest load bank technology and repeatedly runs load tests offers many advantages in terms of reliability, cost, and safety. ComRent can shorten the elapsed time of the load test by reliably bringing the appropriate equipment in a narrow time window. Most of all, using the latest load bank technology will reduce overall commissioning costs.

6. APPENDICES

Appendix A - Electrical Power Testing References

Appendix B - Definitions and Acronyms

Appendix C - Description of Power Testing Program

Appendix D - Tools for Structured Problem Solving

Appendix E - Framework for Describing Energy Sources

Appendix F - Inspections and Tests

Appendix A - Electrical Power Testing References

The following publications can provide some of the job knowledge required by an electrical power testing technician career.

ANSI/NETA MTS-2015 - STANDARD FOR MAINTENANCE TESTING SPECIFICATIONS for Electrical Power Equipment and Systems

ANSI/NETA ATS-2009 - STANDARD FOR ACCEPTANCE TESTING SPECIFICATIONS for Electrical Power Equipment and Systems

ANSI C84.1-2011
American National Standard for Electric Power Systems and Equipment— Voltage Ratings (60 Hertz)

ASHRAE Guideline 0-2013-- The Commissioning Process

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Appendix B Definitions and Acronyms

Anti-Islanding Test: A test that confirms the function of disconnecting and reconnecting when the utility source power is lost. This is typically used for Inverters and is required under UL 1741.

Area electric power system operator (Area EPS Operator): The entity responsible for designing, building, operating, and maintaining the Area EPS.

As-found: Condition of the equipment when taken out of service, prior to testing.

As-left: Condition of equipment at the completion of inspection and testing. As-left values refer to test values obtained after any corrective action or design change has been performed on the device under test.

Backfeed: Electric power flow from the generation unit into the utility source.

Breaker Failure: Condition where a circuit breaker or switch does not operate properly after receiving a signal to operate.

Cease to energize: Cessation of energy outflow capability.

Clearing time: The time between the start of the abnormal condition and the distributed resources' (DR's) ceasing to energize the area electric power system (EPS). It is the sum of the detection time, any adjustable time delay, the operating time for any interposing devices (if used), and the operating time for the interrupting device (used to interconnect the DR with the area EPS).

Commissioning test: A test conducted when the equipment is installed to verify correct operation

Design test: Test of one or more devices made to a certain design to show that the design meets certain specifications.

Continuous Commissioning™: Continuous commissioning™ refers to a commissioning approach that is integrated into a facility's standard O&M program. As such, activities in support of the continuous commissioning™ effort are completed on a regular basis, compared to recommissioning approaches that tend to be distinct events. The continuous commissioning™ (CC) approach developed by the Energy Sciences Laboratory at Texas A&M University is a formalized continuous commissioning™ approach and is defined as "an ongoing process to resolve operating problems, improve comfort, optimize energy use and to identify retrofits for existing commercial and institutional buildings and central plant facilities" (Texas A&M 2002). Continuous commissioning™ is the most costly existing building commissioning approach due to necessary allocations of staff and equipment; however, the higher costs can work to identify equipment inefficiencies as they occur, allowing for quick remediation, greater energy and cost savings, and better building services. By definition, continuous commissioning™ works to ensure more stable building operations over time than the recommissioning approaches.

Distributed generation (DG): Electric generation facilities connected to an Area EPS through a PCC;
a subset of DR.

Distributed resources (DR): Sources of electric power that are not directly connected to a bulk powertransmission system. DR includes both generators and energy storage technologies.

Design test: See: type test.

Detection time: The minimum length of time from the inception of the abnormal condition to the change in state of the device or function dedicated to controlling the interrupting device. Syn: processing time.

Distributed generation (DG): Electric generation facilities connected to an area electric power system
(EPS) through a point of common coupling (PCC); a subset of distributed resources (DR).

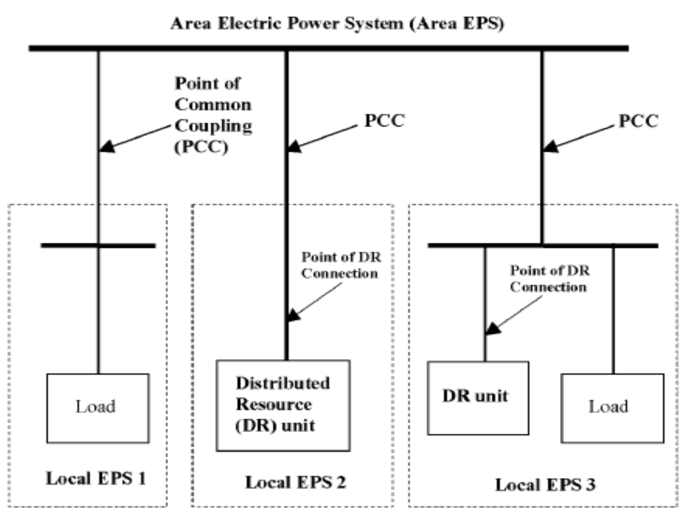
Distributed resources (DR): Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.

See Figure 1 for Illustration.

3.1.4 distributed generation (DG): Electric generation facilities connected to an Area EPS through a PCC; a subset of DR.

3.1.5 distributed resources (DR): Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.

NOTE—See Figure 1 and Figure 2.



Electric power system (EPS): Facilities that deliver electric power to a load. Note that EPS may include generation units. See also: area electric power system (EPS); local electric power system (EPS).

Fault: An unintentional high current resulting from any of several possible unusual conditions such as a short-circuit or a loss of conductor insulation.

Fault Current: Measurement of available fault current used to activate sensors and switches in a utility distribution network.

Differential: The difference between two measured characteristics of the system. These characteristics are normally similar in magnitude.

Electrical tests: Electrical tests involve application of electrical signals and observation of the response. It may be, for example, applying a potential across an insulation system and measuring the resultant leakage current magnitude or power factor or dissipation factor. It may also involve application of voltage and/or current to metering and relaying equipment to check for correct response.

Equipment condition: Suitability of the equipment for continued operation in the intended environment as determined by evaluation of the results of inspections and tests.

Exercise: To operate equipment in such a manner that it performs all its intended functions to allow observation, testing, measurement, and diagnosis of its operational condition.

Extra-high voltage: A class of nominal system voltages greater than 230,000 volts.

Feeder: The circuit that feeds power to a facility. Branches of circuits radiating from a utility distribution substation are called feeders.

Field Regulator: The generator voltage at a predetermined level when isolated from the electric utility and maintain preset VAR flow when connected with the utility electric service.

Generation Unit: Assembled package including the prime mover, generator, and auxiliary devices that are normally operated together as a single source of power.

Generator: Device driven by a prime mover that converts mechanical energy into electrical energy.

Governor: Electro-mechanical system for controlling the prime mover and generator speed when isolated from the utility service and controlling the generator load when paralleled with the utility service.

High voltage: A class of nominal system voltages equal to or greater than 100,000 volts and equal to or less than 230,000 volts.

Inspection: Examination or measurement to verify whether an item or activity conforms to specified requirements.

Instantaneous: The shortest operating time available for a protective device. Generally recognized as having no intentionally added time delay.

Interconnection: The combination of the electrical utility service and the on-site generation unit feeder into a single coordinated sys- tem supplying common loads.

Interconnection system (ICS): the collection of all equipment and functions, taken as a group, used to interconnect a distributed resources (DR) unit to an area electric power system (EPS).

Interconnection equipment: Individual or multiple devices used in an interconnection system.

Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect a DR unit(s) to an Area EPS.
NOTE—See Figure 2.

Figure 2—Schematic of interconnection

Interrupting device: A device capable of being opened and reclosed whose purpose is to interrupt faults and restore service or disconnect loads. These devices can be manual, automatic, or motor-operated. Examples include circuit breakers, motor-operated switches, and electronic switches.

Inverter: A machine, device, or system that changes direct-current power to alternating-current power.

Island: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS.

Island, intentional: A planned island.

Island, unintentional: An unplanned island.

Islanding: Continued operation of a generation unit while isolated from the rest of the interconnected utility service.

Isolate: Disconnect a generation unit, utility service, or load from the electrical system.

Local electric power system (EPS): An EPS contained entirely within a single premises or group of premises.

Lock Out: Prevent a device from per- forming an undesired operation by using a mechanical or electrical means.

Mechanical Interlock: The means of restricting operation to a desired pattern using a system of mechanical locks, often with controlled keys.

New Building Commissioning: New building commissioning (Cx) is a means to ensuring through design reviews, functional testing, system documentation, and operator training that systems and equipment in new buildings are operating properly.

Nominal: The value or range of a parameter being within expected norms or being the normal operating level of that parameter

Non-islanding: Intended to prevent the continued existence of an island

Offline Test: Testing equipment while it is removed from its normal operating environment.

Online Test: Testing equipment while it is connected with its normal operating environment.

Operations and Maintenance: The decisions and actions regarding the control and upkeep of
property and equipment. These are inclusive, but not limited to, the following: 1) actions focused on
scheduling, procedures, and work/systems control and optimization; and 2) performance of routine,
preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or
decline with the goal of increasing efficiency, reliability, and safety.

Operational Efficiency*:* Represents the life-cycle, cost-effective mix of preventive, predictive, and
reliability-centered maintenance technologies, coupled with equipment calibration, tracking, and
computerized maintenance management capabilities all targeting reliability, safety, occupant comfort,
and system efficiency.

Overcurrent: Any current greater than the rated current of a conductor, component, or equipment. Causes include overload, ground fault, and short circuit.

Over frequency: Any frequency greater than the rated frequency of an alternating current system.

Overvoltage: Any voltage greater than the rated voltage of a system.

Overspeed : Any rotational velocity greater than that desired of a system.

Paralleling: Connecting separate electrical services after confirming they are in synchronization.

Paralleling device: A device (e.g., circuit breaker) operating under the control of a synchronizing function to electrically connect two energized power sources together.

Point of common coupling (PCC): The point where a local electric power system (EPS) is connected to an area EPS.

Point of distributed resources (DR) connection: The point where a DR unit is electrically connected in an electric power system (EPS).

Prime Mover: The mechanical device driving a connected generator to pro- duce electrical power.

Production test: A test conducted on every unit of equipment prior to shipment.

Programmable Logic Controller: Micro-processor device for controlling other hardware to accomplish specific tasks or processes.

Reclose: Reconnect the generation unit with the utility electrical service. This operation is initiated by the protective system for isolation or islanding

Recommissioning: Recommissioning (RCx), which is sometimes referred to as “retrocommissioning,” is the practice of commissioning existing buildings – testing and adjusting the building systems to meet the original design intent and/or optimize the systems to satisfy current operational needs. RCx relies on building and equipment documentation, along with functional testing to optimize performance.

Signal injection test methods: Test methods where signals are injected into the sense terminals of the equipment under test (EUT). These methods include both primary injection test methods and secondary

Simulated area electric power system (EPS): An assembly of voltage and frequency test equipment replicating a utility power source. Where appropriate, the actual area EPS can be used as the simulated area EPS.

Simulated utility: See: simulated area electric power system (EPS).

Synchronize: Process for adjusting separate electric services until they possess identical electrical components of voltage, frequency, and phase rotation.

Time-current Curve: Graph showing the characteristic performance of a device as related to time and current. Generally used for choosing components of a coordinated system protection.

Time Delay: The time elapsed between a device receiving an operating signal and the device's output transmission.

Total rated-current distortion (TRD): The total root-sum-square of the current harmonics created by the distributed resources (DR) unit operating into a linear balanced load divided by the greater of the test load current demand IL or the rated-current capacity of the DR unit Irated.

Trip time: The interval that begins at the leading zero-crossing of the first half cycle of the voltage waveform in which the measured parameter (e.g., frequency, voltage, power) exceeds the trip limit and ends when the equipment under test (EUT) responds as required.

Type test: Test of one or more devices made to a certain design to demonstrate that the design meets certain specifications. Syn: design test. E.g. UL 1741 Inverters.

Undercurrent: Any current less than the rated current of a conductor or equipment.

Underfrequency: Any frequency less than the rated frequency of a conductor or equipment.

Undervoltage: Any voltage less than the rated voltage of a conductor or area electric power system (EPS): An EPS that serves local EPSs. Note that, typically, an area EPS has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight.

Value Recommissioning: Value recommissioning (VCx) is the lowest cost option that focuses on the most common opportunities, ideally incorporating them into daily operating procedures. VCx is the least comprehensive and requires the least specialized skill set. VCx concentrates on the most common opportunities that typically carry the shortest payback periods. Therefore, VCx is best applied in buildings where resources for structured recommissioning or continuous commissioning™ programs are not available. In addition to realizing highly cost-effective energy savings, tracking benefits (i.e., energy savings, cost savings, and reduced occupant complaints) of VCx activities can be helpful in developing justifications for funding requests of the more robust commissioning approaches.

List of Acronyms

Cx Commissioning Agent

PM Preventative Maintenance Program

DER Distributed Energy Resources

V Volts

kW Killowatts

MW Megawatts

CT current transformer

d.p.f displacement power factor

DR distributed resources

EMI electromagnetic interference

EPS electric power system

EUT equipment under test

ICS interconnection system

PCC point of common coupling

p.f power factor

PUT parameter under test

RLC resistance, inductance, and capacitance

Rms root mean square

THD total harmonic distortion

TRD total rated-current distortion

Common ANSI/IEEE Reference Numbers Used for Protective Relays in Distributed Energy Resources

25 – Synchronizing or Synchronism-Check Device

27 – Undervoltage Relay

29 – Isolating Contactor or Switch

32 – Directional Power Relay

40 – Field (over/under excitation) Relay

46 – Phase-Balance Current Relay

47 – Phase-Balance Voltage Relay

59 – Overvoltage Relay

67 – AC Directional Overcurrent Relay

81 – Frequency Over/Under Relay

Protective relays: Protective relays function by processing an input signal into an output signal. The process usually is triggered by the input signal meeting or exceeding a set parameter limit. The process output signal is then transmitted either instantaneously or after a preset time delay. This output signal is used to activate another device, either another relay or a mechanical disconnecting means. Protective relays perform either a single function or multiple functions depending on the manufacturer and the design engineer's preference.

Synchronizing Relay (25): Function triggered when either phase angle or slip frequency equals preset levels. This is sometimes called a sync check relay

Undervoltage Relay (27): Function triggered when voltage is below a preset level.

Directional Power Relay (32): Function triggered when power in a particular direction is above a preset level.

Undercurrent Relay (37): Function triggered when current is below a preset level.

Reverse Phase Voltage Relay (47): Function triggered when phase rotation is different than the specified direction.

Instantaneous Overcurrent Relay (50): Function triggered when instantaneous current is above a pre-set level.

Time Overcurrent Relay (51): Function triggered when time current is above a preset level.

Overvoltage Relay (59): Function triggered when voltage is above a preset level.

Directional Overcurrent Relay (67): Function triggered when current is above a preset level in the specified direction.

Reclosing Relay (79): Function triggered by a signal from the voltage sensors.

Overfrequency Relay (81O): Function triggered when frequency is above a preset level.

Underfrequency Relay (81U): Function triggered when frequency is below a preset level.

Lock Out Relay (86): Trips the generator circuit breaker open and prevents automatic reset.

Breaker Failure Relay (BF): Senses when the generator circuit breaker has not operated despite having received a signal to operate.

Generator Circuit Breaker (52G): Switchgear- mounted circuit breaker with electrically operated spring charging mechanism, remote tripping, remote closing, and backup tripping system (either capacitors or batteries) for operation during complete loss of normal power.

Appendix C - Description of Power Testing Program

System Test Requirements and Process

2. Testing Process

a) Engine Generators

(1) System provides rated emergency power within 10 seconds of power outage

(2) In some systems there may be requirements for stepping up the load in defined increments

(3) Particular attention is paid to the transient periods

(4) Engine generators are rated based on the anticipated run time:

> *Continuous – Significant lower rating of Generator*
>
> *Prime Power – 70% Power Rating – typically limited to 2500 hours per year*
>
> *Standby – 100% Power Rating -Typically limited to 100 hours per year*

b) Paralleling Switchgear

(1) System provides paralleling of AC Synchronous Generators within 10 seconds by controlling the generator circuit breakers

(2) System Provides soft transition to/from grid power by controlling the main and tie breakers

(3) System performs the required protective relay functions specified by the utility

(4) System performs self-protection functions

(5) System provide critical load management functions

c) Automatic Transfer Switches

(1) Multiple switches are to transfer loads to/from energized circuit as specified by the Paralleling Switchgear or PDU

(2) Maintain switch position under abnormal conditions

(3) Sequence of operation for load isolation is critical

d) System Level Functions

(1) The testing should validate that the system performs the correct sequence of operation in the various conditions set by the facility designers

> *Coordination with the electric power provider for the facility may be needed. For example coordination of the protective relays on the facility with the distribution circuit connected to the facility may be required.*

B. Special Considerations

1. DC Power Distribution

a) Limited to 600V or special layout and shielding required

b) Consensus standards not yet developed

2. Medium Voltage (12kV to 69kV)

a) Full load commissioning tests can be performed using medium voltage equipment
b) Greatly reduces complexity and space required for the test
3. Ancillary Services
a) Voltage Regulation
b) Frequency Regulation
c) Harmonic Filtering
d) Power Factor Correction

C. Load Testing Innovations

1. Technology can accelerate schedule and reduce total cost
2. Medium Voltage Load Banks
a) More realistic to test medium voltage generators with MV load banks
b) Require 15x fewer cables and 5x less time to set up and tear down
3. Movable Transformers
a) Transformers are available that are configured to be moved to a site for temporary use. These may include shipping cages, fork lift slots, and multiple tap orientation.
4. Specialty Load Banks
a) Server Rack Mounted Load Banks
b) Liquid Cooled Load Bank
c) Multiple small load banks ganged to simulate large load
5. Power Quality Testing
a) In most cases, three pieces of equipment are required:
(1) Power Quality Monitor
(2) Data Recorder- monitors recovery time up to 10 second
(3) Harmonic Logger
b) Recently, integrated Power Quality Monitors have become available that complete more tests in less time, collect more data and reduce report generation time. This allows the facility manager to focus on the data and plausible solutions in less time.
6. Advanced Communication and Control
a) Remote Control – reduce time and associated man hours to complete tests
b) Full Network Integration and Remote Control
(1) Network Management controls are available that fully integrate all load bank functions, controls, operations, and reporting into the Network Management System, so that the load bank can be operated remotely from the Network Operations Center. All data is collected and integrated directly into the SCADA System.

Appendix D - Tools for Structured Problem Solving

1. **Recognize the problems**
2. **Establish the team**
3. **Problem Description** -- Describe the problem in measurable specific terms.
4. **Containment** --Define and implement those intermediate actions that will reduce incidence of failure until permanent corrective action is implemented. Verify with data the effectiveness of these actions.
5. **Determine Root Causes** --Identify potential causes which could explain why the problem occurred. Test each potential cause against the problem description and data. Identify alternative corrective actions to eliminate root cause.
6. **Select & Verify Corrective Action** --After root causes and possible corrective actions have been identified, select the corrective actions that will permanently correct the problem. Verify that the selected corrective actions will resolve the problem. Validate the test solution is close to operating conditions.
7. **Implement and Validate Corrective Action** -- Implementation can proceed when the best corrective action has been selected and verified. Validation is obtained by tracking performance over time after implementation to ensure the corrections are permanent. Ensure that the corrective action does not affect other parts of the system or that the impact will be minimized by changes to other parts of the system.
8. **Prevent System Recurrence** -- Be able to answer the following questions. Have the system prevention practices, procedures, and specification standards that allowed the problem to occur been identified? Does the organization have the expertise to implement and maintain the solution? Has a person been identified who is responsible for implementing the system preventive action? Does the preventive action address a large scale process in a business, manufacturing, or engineering system? Has the preventive action been built to operating specifications? Have the systems been tested under real- world operating conditions?
9. **Congratulate the Team and recognize the effort and success of team members** - Share your knowledge of the benefits of load testing and preventive maintenance with other areas of the enterprise.

	D1: Team Approach
Define	D0: Recognize Problem D2: Describe Problem D3: Containment
Measure Analyze	D4: Define & Verify Root Causes
Improve	D5: Select & Validate Corrective Actions D6: Implement Corrective Actions
Control	D7: Prevent Recurrence
	D8: Congratulate Team

Appendix E - Inspections and Tests

RecommendedInspections and Tests Frequency (Months)

Description	Visual	Visual & Mechanical	Visual & Mechanical & Electrical	Functional Load Test
Switchgear & Switchboard Assemblies	12	12	24	36
Transformers				
Small Dry-Type Transformers	2	12	36	
Large Dry-Type Transformers	1	12	24	
Liquid-Filled Transformers	1	12	24	36
Cables				
Low-Voltage Cables	2	12	36	
Medium- and High-Voltage Cables	2	12	36	36*
Metal-Enclosed Busways	2	12	24	
Switches				
Low-Voltage Air Switches	2	12	36	24
Medium-Voltage Metal-Enclosed Switches	-	12	24	24
Medium- and High-Voltage Open Switches	1	12	24	24
Medium-Voltage Oil Switches	1	12	24	24
Medium-Voltage Vacuum Switches	1	12	24	24
Cutout Fuse	12	24	24	24
Circuit Breakers				
Low-Voltage Insulated-Case/Molded-Case CB	1	12	36	36
Low-Voltage Power CB	1	12	36	36
Medium-Voltage Air CB	1	12	36	36

Paper Submitted by:

Mark Siira
Director of Business Development
ComRent Internationa
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