COMMISSIONING
COMBINED CYCLE POWER PLANTS

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Preface

This paper outlines a program that will successfully commission a combined cycle power plant. Commissioning personnel, plant owners, operators, and others will benefit from the lessons learned and experiences discussed in this paper. Engineering and construction personnel who interface with the commissioning team may also see how their work influences the commissioning effort.

There are several ways to commission a power plant, all of which will get the job done. Each project is unique in its contract requirements, specifications, and commercial aspects, so commissioning personnel must have a flexible approach to their work. This paper does not espouse any particular method of commissioning a plant, but instead highlights some of the varied approaches.

Company Background

*Granite Services, Inc* has been a valued supplier to the global power generation industry since 1990. Granite Services, Inc is certified to ISO 9001:2000 and employs over 3,000 engineers and technicians, with services in commissioning, operations, maintenance, and training. Our safety record is superlative.

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## Introduction

A combined cycle power plant (CCPP) has one or more combustion turbine generators (CTG’s), corresponding heat recovery steam generators (HRSG’s), and one or more steam turbine generators (STG’s). A new CCPP has the following phases: contract negotiation, design, procurement, construction, commissioning, and operation. The commissioning of the CCPP is the final quality check of all the previous processes.

### Table 1, Commissioning Steps

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The safety of site personnel is the highest priority for the commissioning team. They ensure the safety equipment is ready, such as eye wash stations, safety showers, and firefighting equipment. They train the site personnel to perform work in compliance with the safety program.

## Design and Procurement Phases

The commissioning team works in the office of the architect/engineering (A/E) company during the design and procurement phases of the project. We recommend one or two trips to the CCPP during this phase, to assess construction status. The team performs the following steps while in the office.

### 1.1 Contract Review

The commissioning team reviews the project contract. They identify the commissioning deliverables, milestone activities, inspection and test requirements, safety requirements, budget allowances, training requirements, craft support, and vendor representative requirements.

### 1.2 Schedule

The commissioning team reviews the project schedule and integrates the commissioning activities. The team merges each system turnover date within the project schedule. The high priority schedule activities are temporary power or backfeed power, HRSG chemical cleaning, steam blow of the steam piping, loop checks, first fire of the CTG’s, condenser vacuum and rolling the STG, synchronizing the generators, scheduled outages, full load testing, and commercial operation. During the commissioning phase, the commissioning team constantly checks their progress against the planned schedule, and makes improvements as necessary. (Note: The schedule in Figure 1 is for display only, and does not represent any particular plant.)
1.3 **Budget**

The commissioning costs are: manpower and duration; personnel expenses, such as salaries, transportation, per diem, and living accommodations; vendor representatives; craft support; chemical cleaning; consumables; chemicals; lubricants; spare parts; tools; equipment; security; and contingencies.

1.4 **Project Review**

The commissioning team reviews the project design using the piping and instrumentation diagrams, electrical one-line diagrams and schematics, logic diagrams, and vendor manuals. They assess commissioning feasibility, operability, and maintainability. They collect lists for mechanical and electrical equipment, instruments, and piping, in order to build the turnover packages. The commissioning team also reviews the water sources; the disposition of waste water; tempo-
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rary equipment; fuel specifications and consumption; maintenance requirements; interface be-
tween the new project, the electrical transmission system, or an existing project. They also re-
view the schedule for inspectors from government agencies or insurance companies.

1.5 System Turnover Packages

The commissioning team marks engineering drawings with the boundaries of each system. They
identify all the equipment, pipes, cables, and instruments in each system. At the jobsite, the con-
struction team adds their inspection and test records to these packages. (See Figure 2.) After the
system turnover, the commissioning team will control the records in the packages.

Figure 2 - System Turnover Package

1.6 Commissioning Manual

The commissioning team creates the commissioning manual and maintains document control.
The manual contains:
• Procedures for safety tagging, work permits, hot work permits, fire protection measures, safety equipment, and confined space entry.
• The “Matrix of Responsibilities,” which determines the scope of work between construction and commissioning. The commissioning team identifies the responsibilities of each project team member (A/E, construction, commissioning, and plant owner).
• Administrative procedures. The system turnover interface needs to be very clear. The plant owner reviews and may approve the commissioning data.
• Procedures to attain and verify the cleanliness level required for each system piping and equipment.
• Procedures to demonstrate that each system operates within design parameters.
• Procedures for electrical power to the switchyard or substation and to the plant distribution system; also a procedure to track jumpers and lifted leads.
• Checklists for instrument calibrations and loop checks.
• Integrated tests of the entire facility (all systems in operation).

The A/E team specifies the test criteria: (1) calculated, (2) international or national standards, or (3) the vendor’s specification. The A/E electrical engineer specifies the meter and relay settings in the relay coordination study. The A/E instrument engineers provide instrument calibration set points. The A/E mechanical engineer determines the systems’ cleanliness criteria, material or flow balances, and vibration criteria.

1.7 Purchasing and Subcontracts

The commissioning team reviews the vendor representative requirements and arranges for the vendors to arrive at the job to meet the schedule. Some vendor representatives are included in the original equipment purchase orders while others may be subcontracted by the commissioning team.

The team prepares requisitions or rental agreements: craft support, chemicals, lubricants, test equipment, chemical analysis equipment, water supply, fuel supply, tools, storage containers, temporary pumps, spare parts, consumables, vehicles, office space, radios, and transportation for personnel. They also setup subcontracts for electrical testing, HRSG chemical cleaning, instrument calibration, and other services, as required. They will also need office space, communication equipment (phones, facsimile machines), equipment storage, and a laydown area.
1.8  **Training**

Some clients purchase training for their operations and maintenance personnel. The commissioning team develops the schedule and format for the training, selects required vendors or training agencies, and generates the training manuals.

2  **System Turnover (from Construction to Commissioning)**

2.1  **System Turnover Packages**

The construction team builds the power plant by area (e.g., the fuel storage area). As work progresses, the construction team changes their focus to systems (e.g., the fuel oil forwarding system). When a system is “mechanically complete,” the construction team completes the system turnover package and submits the package to the commissioning team.

2.2  **System Walk Down**

A joint construction and commissioning walk down of the system verifies all work within the boundaries is complete. Any incomplete work items go into the punch list. The construction team finishes those items later, under the commissioning work permit program.

2.3  **Punch List**

The punch list records each non-conformity. It shows the system, the component tag number and description, a definition of the discrepancy, the work group responsible for fixing the deficiency, and the dates that the item was generated and closed.

Project management integrates the punch lists from the various work entities into one master list, to optimize the scheduling of equipment and manpower.

3  **Component Testing**

Depending on the contract, the construction team performs some of the component tests and the commissioning team performs others. Some tasks may be subcontracted. The project management reviews the “Matrix of Responsibilities” and each organization’s goals.
3.1 **Nameplate Data**
Before testing any component, verify the nameplate data against the design documentation.

3.2 **Alignment**
Align rotating equipment to the manufacturer’s tolerances before operation.

3.3 **Lubrication**
Lubricate equipment before commissioning. Follow the manufacturer's instructions. Equipment may have a factory-installed lubricant that protects the equipment during shipping and storage. Replace factory lubricant with the normal lubricant.

3.4 **Pumps**
Review the vendor manual before operation. Verify the correct direction of rotation for the pump and the driver. Test pumps in accordance with a standard test program. Compare centrifugal pump capacity versus the head on the pump curve. Test positive displacement pumps for the capacity measurement by volume rate of flow.

3.5 **Flushing**
If possible, inspect the pipes prior to welding to guarantee there are no foreign objects in the pipe. In cold climates check the freeze protection prior to filling any liquid systems. Before flushing, bypass any heat exchangers to prevent debris from entering. Because the flow rate drops in the heat exchangers, any debris will settle, and the heat transfer capability of the heat exchangers is diminished. Remove instruments, orifice plates, and control valves prior to flushing. If the installed pumps are not ready for flushing, use temporary pumps instead. Flush the pipes, and inspect the system for cleanliness verification. Restore the system and make preparations for system operation.

For some systems, chemical cleaning may be faster than flushing with the process fluid.

3.6 **Heat Exchangers**
Tighten the bolts on one end of a heat exchanger, and ensure the other end is free to travel for thermal expansion, per the vendor instructions. Check the bolts during the initial inspection. Even large heat exchangers, such as air-cooled condensers, must be checked for movement.
3.7 Cleaning of HRSG’s and Steam Headers

After hydrostatic tests, clean the HRSG’s. The traditional cleaning cycle: degrease, perform citric acid cleaning; rinse; run CTG’s; clean the steam headers by steam blows; bypass the STG until chemistry is satisfactory; and send steam to the STG. The drawback is high water usage.

An alternative: degrease, clean the HRSG’s and the steam system with hydrofluoric (HF) acid, rinse, run CTG’s, bypass the STG until chemistry is satisfactory, and send steam to the STG. This method has a shorter duration on the schedule. The drawback is the safety issues of HF.

Another alternative: rent air compressors, pressurize the HRSG’s with air, and use a quick-opening valve to blast the pipes. Air blows can also shorten the overall schedule since the blows are conducted off the critical path. The drawback is the cost of the air compressor rental.

3.8 Motors

Energize the internal heaters on large motors, generators, and motor-operated valves with temporary power, until permanent power is available. Verify insulation resistance of large motors and generators. Uncouple electric motors, check lubrication, and verify proper motor rotation and vibration. Couple the motors. Check motor parameters again during normal operation.

3.9 Cables, Switchgear, and Motor Control Centers (MCC’s)

Test cables for continuity and insulation resistance. Perform hi-pot testing on switchgear and MCC’s. Test breakers and switches. Verify all alarms, interlocks, and trip circuits.

3.10 Transformers and Switchyards

A subcontractor or other third-party inspects and tests the transformers, bushings, circuit breakers, and disconnect switches. Condition the oil in oil-filled transformers, HV bushings, and circuit breakers to remove vapors and water. Test all disconnect switches.

3.11 Electrical Meters and Relays

A subcontractor or third party calibrates and tests the meters and relays. Lookup the set points for trips and alarms in the design engineer’s coordination study.

3.12 Maintenance

The commissioning team performs maintenance, and they train the plant maintenance personnel.
3.13 **Instrumentation**

Inspect and calibrate the instruments in the shop. The instruments may also be calibrated in–situ.

3.14 **Loop Checks**

There are thousands of loops in a CCPP, depending on the design and degree of automation. Provide the correct number of experienced personnel to complete the loop checks on schedule. Perform loop checks from “end to end,” from the instrument to the control system and then to the control device. Test all control, alarm, and trip signals before operation.

3.15 **Training**

The commissioning team and vendor perform classroom training and on-the-job training for the plant operators and maintenance personnel during the component testing.

4 **System Commissioning**

When starting systems, start them by “group.” The cooling water group might be circulating water (CW), auxiliary cooling water (ACW), and closed circuit cooling water (CCCW). Another group might be the condensate and feed water systems. This technique speeds up the schedule, since the similar systems will work together quicker if handled as a group.

4.1 **DC Power and UPS System**

Direct current (DC) power is the first electrical system to energize. The specifications may require a load test on the DC system. The commissioning team rents load banks for this test. Apply temporary power to the battery chargers. Ventilate the battery room to exhaust hydrogen gas from the charging process. Verify an eyewash station is available for personnel safety. Now start testing the electrical distribution switchgear controls and meters and relays.

Connect a temporary power supply to the uninterruptible power supply (UPS) backup, for emergency power. Now begin the controls systems commissioning.
4.2 **Initial Electrical Power**

Energizing the plant distribution system requires planning between the plant and the local transmission system. Due to the schedule, backfeed power may not be available to support commissioning. In that case, rent diesel generators and transformers to provide temporary power. Other systems may also require temporary power (e.g., CTG lubricating oil pump).

4.3 **Distributed Control System**

Perform the checkout of the distributed control system (DCS). Check the DCS ground connection. Energize each processor and load software. Setup the human machine interface. Perform component and functional checks. Establish communications with other control systems. Perform loop checks. Conduct loop tuning as systems become operational.

4.4 **Instrument Air/Service Air**

The first mechanical system in operation is the instrument air system. Inspect the moisture traps on the discharge of the air compressor. Make sure they are installed correctly and operating. Monitor the system humidity indicator. While blowing the air distribution piping, monitor the air dryers for excessive flow rates. Blow the piping until clean, dry air is ready at each instrument.

4.5 **Water Treatment**

The second mechanical system in operation is the water treatment system. Prior to adding the resin to a demineralizer vessel, inspect the vessel interior and the resin screens. Test the regeneration control sequence, adjust the rinse rates, and adjust the chemical dilution rates. Purchase an eductor to sluice the resin into the vessels. Verify the safety eyewash and showers are available for use. Ensure all required chemicals are on hand.

Clean the chemical feed systems meticulously prior to operation. Any debris in the piping can upset the diaphragm-type pumps. Provide the proper chemical analysis equipment. A rented cargo container often suffices for a temporary chemistry laboratory, with the various utilities connected.

4.6 **Waste Water Treatment**

At “zero discharge” projects, the waste water treatment system can be complex. Do not underestimate the manpower to commission and maintain the system. Test all sumps for proper alarm
and pump control. Test the oily water separating device early in the commissioning sequence, since there may be some oil in the sumps.

![Diagram of CCPP Prime Movers and Balance of Plant Systems](image)

**Figure 4 - CCPP Prime Movers and Balance of Plant Systems**

### 4.7 Fire Detection and Protection

The installation subcontractor tests the fire detection system. Inspect or test all sprinklers, deluge valves, and gas discharge systems. A government inspector or an insurance company inspector may witness the testing.

After the water supply system is running, start the fire pumps. Place the motor-driven and/or diesel-driven fire pump in the automatic mode. Monitor the jockey pump for frequent cycling; it may mean there is a leak in the fire main. Calibrate the post indicator valves to show the correct position.

Test the CTG’s fire suppression systems, such as CO₂ or FM200, before initial operation. These systems may be in the control cabinet or in the turbine housing.

### 4.8 Cooling Water

Verify the circulating water pump discharge valve sequence prior to starting the pump. Throttle the outlet valves on the water boxes to set the proper flow. Circulating pump seal water, for lubrication of the pump packing, may need a temporary backup system. The water boxes may have sacrificial zinc anodes. Check the anodes after initial operation for integrity. Inspect fittings on the seawater side. Make sure materials are compatible with seawater. Install corrosion coupons. Start any cathodic protection systems as soon as the system is filled with seawater.
If there is a water box priming system, start it early in the program. Otherwise, air pockets prevent the tubes from filling with seawater.

If the project has cooling towers, inspect the spray nozzles, distribution headers, and “fill” material before starting. After the first use, check again to make sure there are no problems created by the force of the water, such as loose fittings. Monitor pump strainers closely. Check cooling tower fans for vibration and monitor gearboxes for proper lubrication. Place a wooden cooling tower’s fire protection system in service as soon as possible. Once a wooden cooling tower is put in service, keep it wet so that it does not dry out and become a fire hazard.

4.9 Steam, Feed Water, and Condensate

Test the condensate pumps and the control valves. Some pumps require an external source of seal water, and may require installation of a temporary system.

Inspect the deaerator before use. Install the trays in the proper orientation. Remove the spray nozzles. Flush the piping into and out of the deaerator. Inspect the deaerator again. Remove any debris from the storage vessel. Install the spray nozzles. After initial operation, inspect the deaerator one last time. Check the spray nozzles and trays.

Monitor the strainer feed water pump suction strainer carefully during initial operation. Inspect the minimum flow valve and any minimum flow orifices to make sure the recirculation flow is proper. If the pump has an automatic recirculation valve in the discharge, remove the valve for the initial operation, or (in some cases) install a special “commissioning trim” for initial operation.

Inspect all steam traps for proper cycling. After initial operation, disassemble and clean steam traps that have internal strainers. Traps that don’t operate properly can cause bigger problems.

4.10 Heat Recovery Steam Generators

Test all valves and pumps on the HRSG’s. Test the duct burner controls. Some plants run the CTG in “simple cycle” mode by means of a stack damper and a bypass stack. Test the stack damper for any leakage into the HRSG. Check all interlocks and alarms. Inspect all safety valves, exhaust piping, silencers, and any associated drain piping.

If the CTG’s burn crude oil or some other heavy oil, the HRSG’s may have soot blowers. The alignment and lubrication of the lances are critical to smooth operation.
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4.11 **Sample Panels**

Put the sample panels in service after the systems are clean. Until then, create temporary sample coolers. Monitor the pressure regulating valves and other small passages for plugging.

4.12 **Fuel Systems**

Perform leak tests with air before the fuel gas comes inside the plant. Test the installed gas monitor using a calibrated gas. Start the hot work permit program. Purge with nitrogen prior to admitting gas. During operation, verify the fuel gas temperature is above the dew point. If there are liquids in the gas then the expansion at the pressure letdown station causes the temperature to drop. Freezing can occur.

Inspect the coatings and special hardware, such as floating suction apparatus or siphon breakers, prior to filling the tank. Flush the pipes using a high velocity flow. Run the fuel forwarding pumps to flush the oil supply lines to the CTG’s.

4.13 **CTG’s**

In most plants the commissioning of the CTG is the responsibility of the turbine vendor. The vendor representatives test the electrical circuits, run the pumps and fans, flush and clean the systems, and calibrate the instruments. Completed test records go into the CTG turnover package.

For lubricating oil flushing, ensure the area is free of dirt and construction debris (especially the reservoirs and bearings). Install temporary power, lighting, and fire protection. Prepare for oil spills before they happen. Have sufficient adsorbent compound, rags, plastic bags, squeegees, and barrels on hand. Purify the oil before filling the reservoir. Even brand new oil shipments have debris in the oil. Perform the flush. Use temporary pumps and filters for better results. Replace the flushing oil with new oil. Restore the piping.

The turbine control systems need a temporary power supply to checkout the circuits early in the commissioning program.

4.14 **Steam Turbine Generator**

The vendor’s personnel commission the STG. The effort occurs later in the schedule, so permanent power is usually available for testing the STG equipment. Conduct the lubricating oil flush. Test the control systems. Place the turbine on the turning gear for steam blows.
4.15 **Air Conditioning and Ventilation**

Degradation of these systems can have an adverse impact on DCS equipment. Use good quality air filters and replace them regularly. Condenser coils may need frequent cleaning.

4.16 **Piping**

Before the initial heat up, inspect the steam headers, other pipes, and supports. Unlock and adjust all spring hangers. While preparing for CTG first fire, setup the temporary steam piping for the steam blows. Install necessary pipe insulation.

4.17 **Administration**

Every day, the project leaders conduct a commissioning meeting and the commissioning team reviews the “Plan of the Day.” They discuss safety topics, the events planned for the day, and the support required. They determine the expected power output and fuel needs. They monitor the schedule and budget. The commissioning team issues the “two week look-ahead” schedule. Once a week, at the project punch list meeting, the various team leaders review the status of all the punch list items.

4.18 **Training**

The commissioning team trains the operators and maintenance personnel in “hands-on” sessions.

5 **Operational Testing**

5.1 **First Fire**

The CTG is ready for first fire after successfully completing control sequence checks, cranking checks, emergency shutdown checks, false-fire checks, fire detection and protection tests, and turning gear checks. During the first fire operation, vent steam from the HRSG drums and super-heater vents. Perform the various tests in Table 3 during the operational testing phase.

5.2 **Steam Line Cleaning**

After achieving stable operation on the CTG’s, perform steam line cleaning. Calculate the pressure required for each blow. Make targets from polished mild steel or copper. Use jeweler’s rouge to polish them. Place a target in the outlet of the piping. Compare the number and size of impacts on the target to the criteria of the steam turbine vendor. Portable demineralizers may be necessary to produce water for steam blows.
5.3 **STG Bypass**

During operation the steam temperature should not be too high in the superheated region, as the condenser structure may overheat. The steam should not enter the saturated range. This heavier steam may cause aerodynamic problems, cracking of the tubes, or damage to the bypass valve. Dump steam to the condenser until it is clean, and then roll the STG.

<table>
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<th>Table 3, CTG Initial Operation Check List (Typical)</th>
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<td>25 Base load tuning</td>
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<td>28 Liquid fuel FSNL and synchronize</td>
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</tbody>
</table>

**Note:** Some CTG’s may be configured differently.

5.4 **Thermal Expansion**

During the initial heat up verify the proper direction and amount of thermal growth.

5.5 **Generators**

Test the generator excitation, meters, and relays. Verify the trips and interlocks. Perform a pressure test on the hydrogen cooling, purge with CO₂ and pressurize with H₂ to the prescribed concentration. Synchronize the voltage and frequency to the grid. Close the generator breaker.

5.6 **Condenser Operation**

If the condenser has excessive air in-leakage, subcontract a specialist to use a helium detector to detect leakage. Install the detector at the air removal vent. Spray helium on all the joints.
5.7 **Special Situations**

Sometimes it is undesirable to shutdown the plant to fix a leak. Special subcontractors use temporary fittings to stop leaks. These repairs work on high pressure steam systems, circulating water systems, or even cooling systems. Another technique is a “freeze seal.” Liquid nitrogen freezes the process fluid to isolate a section of pipe. “In-place machining” subcontractors repair flanges or valves by bringing their equipment to the plant and performing the repairs in place.

5.8 **Plant Outages**

Some work items require a long shutdown. The schedule includes some long activities, such as removing the strainers from the STG inlet valves, or pulling the strainers from the CTG fuel lines. Schedule the work like a regular plant outage: work permits, materials, and personnel. If the plant trips without notice, perform any known short work items.

5.9 **Performance Testing**

Perform heat rate testing when the plant is new and clean. The protocol from the A/E identifies the temporary and permanent plant instruments to collect data. Calibrate the instruments to validate their accuracy and tolerances. Verify the fuel gas heating value and chemical composition by analyzing actual samples. Calculate the net plant heat rate. If necessary, the A/E supplies correction curves to calculate the adjusted heat rate. Use the data to determine plant performance losses during the life of the plant.

5.10 **Emissions Testing**

The HRSG stack emission testing protocol (prepared by the A/E) validates the emission limit guarantees in terms of nitric oxide (NO) and nitrous oxide (NO₂), or NOₓ; particulates; carbon dioxide; carbon monoxide; excess ammonia slipping past the selective catalytic reduction modules; particulates, in microns; volatile organic compounds (e.g. methane); and sulfur. Local or national agencies specify emissions testing parameters and criteria.

5.11 **Contract Testing**

The contract may require some of the following tests:

5.11.1 **STG and CTG Overspeed Tests**

Perform at least two overspeed tests (one on each circuit).
5.11.2 CO₂ Concentration Tests

Test the CTG fire suppression system by activating the heat detection sensors. Measure the CO₂ concentration in the turbine housing.

5.11.3 Electrical Full-Load Rejection Test

Demonstrate the ability of the CTG’s and the STG to shed load. The turbines should not trip on overspeed and will run down to full-speed-no-load. One of the CTG’s may be configured to runback and implement a safe shutdown.

5.11.4 Duct Burner Testing

Test duct burners at full-fire capability only after the CTG is at base load. For this reason, the duct burners are frequently the last system to commission and are on the critical path to project completion.

5.11.5 Partial Load Stability Test

This test measures the plant’s lowest megawatt output operation. The output should be stable and the stack emissions should stay in compliance with the air permit.

5.11.6 Reliability Test

This test proves the plant can operate continuously, with no emergency trips, for a period of perhaps 7 to 30 days. Other variations of this test: repeated starts and shutdowns, hot and cold re-starts with fast loading, unit maneuvering, STG extraction steam tests, and peaking operation tests.

5.12 Training

The commissioning team trains the operators on steady-state operation, emergency response, and startup and shutdown of the units. The operators should exhibit more self-reliance during this phase, and the commissioning team acts in a more supervisory role.

6 System Turnover (from Commissioning to the Owner)

The turnover from commissioning to the plant owner follows the same methods as the turnover from construction to commissioning.

6.1 System Turnover Packages

Add the commissioning records for each system to the construction packages. Include the completed system procedures, testing data, and the performance test reports.
6.2 System Walk Down

Conduct walk downs in the same manner as those done in the construction turnover. Note any incomplete work on the punch list. Complete those work items later, under the owner’s work permit program. Add the punch list to the package. Verify all work is correct as specified and is ready for client approval.

7 Conclusion

Commissioning personnel started many CCPP’s during the past few years, and the various teams around the world assembled a fairly standard method of commissioning. That method uses the historical groundwork of the electrical utility fossil and nuclear plant commissioning, modified to match the needs of the modern CCPP. Experienced commissioning personnel are ready to meet the future technical demands and challenges.

8 Bibliography

Note: These documents are typical of those that may be used to develop the acceptance criteria for commissioning. Check the individual plant contract to determine which documents are required for the project.


