[redacted]

Commissioning Process Review

Recommendations following whole island Blackout on Bermuda (18/12/2020)

Report for the Regulatory Authority of Bermuda

CONFIDENTIAL VERSION

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1 Introduction

1.1 Objectives and structure of this report

This report has been prepared by [redacted] for the Regulatory Authority of Bermuda ("the RA") following a power system incident that occurred on the 18th December 2020 that resulted in an island-wide power outage. It is the second of 2 reports examining the incident.

The first report:

- Reviewed the information provided by BELCO with regard to the incident;
- Commented on whether the explanations provided by BELCO seem reasonable and adequate; and
- [redacted]

The first review highlighted a number of deficiencies in the commissioning process, leaving latent defects in situ that caused the incident on the 18th of December.

This second report shall:

- Present a commissioning process based on industry best practice which BELCO may consider for any future commissioning activity, including the re-commissioning of the [redacted]
- Discuss the deficiencies observed during the [redacted] commissioning process; and
- Provide recommendations and conclusions.

1.2 Background: Occurrence on the 18th December 2020

On 18 December 2020 at approximately 10:15am an island-wide power outage occurred on Bermuda.

All of the engines at the recently commissioned North Power Station were shut down following a loss of power to [redacted]. The sudden loss of generation at the North Power Station resulted in the remaining available generation being insufficient to meet system demand, resulting in the further tripping of the single running engine at the East Power Station and a Battery Energy Storage System, and a total loss of BELCO owned generation on the island.

Supplies were fully restored at 6.57pm.

Just prior to the system incident BELCO had initiated a scheduled maintenance activity on [redacted] at [sic] North Power Station.

2 Commissioning Process: Fundamental Concepts

2.1 Underlying reporting and documentation requirements

Commissioning can be defined as being the process that must be applied to assure that all system components are designed, installed, tested, operated, and maintained according to the operational requirements of the Asset Owner.

It is therefore important to note that a commissioning regime must accommodate the entire life cycle of a project. It should commence at the design stage of a project and not conclude until after the system has successfully been placed into operational service. At the end of the process a comprehensive suite of operational and maintenance (O&M) documentation should be available and adequate training provided to staff in the operation and maintenance of the installed systems.

The effort required to implement and manage a comprehensive commissioning regime throughout the entire project life cycle should not be under-estimated. It is considered particularly worthy of note that the final stages in the commissioning process are of paramount importance, as in many cases it is the only time when complete systems are installed and all of the interconnections to other systems, provided by other manufacturers or contractors, are able to be proven.

2.2 Commissioning Aims and Objectives

Commissioning can be defined as being the process that must be applied to assure that all system components are designed, installed, tested, operated, and maintained according to the operational requirements of the asset owner. As such it has the aim of proving the technical integrity of equipment, through the rigorous application of the commissioning process.

The objectives of the commissioning process are:

- Verifying that the equipment has not been damaged in transit;
- That it has been correctly installed;
- That it performs as specified;
- Prove that the individual items of equipment, which are interconnected to form circuits and systems are fit for purpose and able to enter commercial service; and
- Obtaining test data for future use (e.g. for comparison in maintenance and fault investigation tasks).

2.3 Commissioning Approach

The tests that are undertaken during Commissioning are commonly divided into two distinct groups:

1. **Off-load commissioning tests or pre-commissioning tests**
   Observing its performance under test conditions, which as far as practicable simulate in service conditions. In instances where it is not possible to conclusively test all aspects of the installation prior to energisation, the tests may need to be limited to those which give a sufficient amount of confidence to allow energisation to proceed.
2. **On load commissioning tests**
   Tests that take place with the equipment energised and connected to the live system.

For example, when commissioning a control system:

- Off-load tests would include artificially simulating Analogues, Alarms and Indications from plant, and confirming they are accurately represented on the control system. Similarly testing of Control actions opening and closing the correct output contacts.
- On load tests would include testing of the real Controls, Analogues, Alarms and Indications between the control system and the installation, confirming accurate representation of conditions and response to instructions.

A methodical, co-ordinated and thorough approach to commissioning is required in order to ensure that all tests are completed in a logical order, with the results being as expected and recorded appropriately. Commissioning engineers should take nothing for granted and should assume “everything is wrong until it has been proven”.

Modern installations such as power stations are very complex, involving many interconnected systems, often supplied and installed by different vendors. Ensuring that all of the systems have been correctly designed, installed and interfaced is therefore paramount. Incorrect commissioning can fail to expose latent defects that sit undetected for long periods until particular combinations of conditions occur.

The impact of commissioning errors are often severe in both financial and reputational damage. It is therefore of increasing importance to learn from the experience of others, and incorporate lessons into commissioning best practice. Regular updating of commissioning practice to reflect current technologies is also required.

3 Best Practice Commissioning Process

3.1 Introduction

The following sections describe how the commissioning aspects associated with large multifaceted engineering projects are typically managed.

It is generally considered that the processes described below form international “commissioning best practice” and have been developed and formally presented within numerous publications and discussion papers over several years.

This report considers those best practices and discusses how adhering and implementing them may have prevented some of the systematic commissioning failures observed from the documentation review summarised within report 1.

Figure 3.1 below portrays the flow of expected commissioning activities throughout the entire project life-cycle.

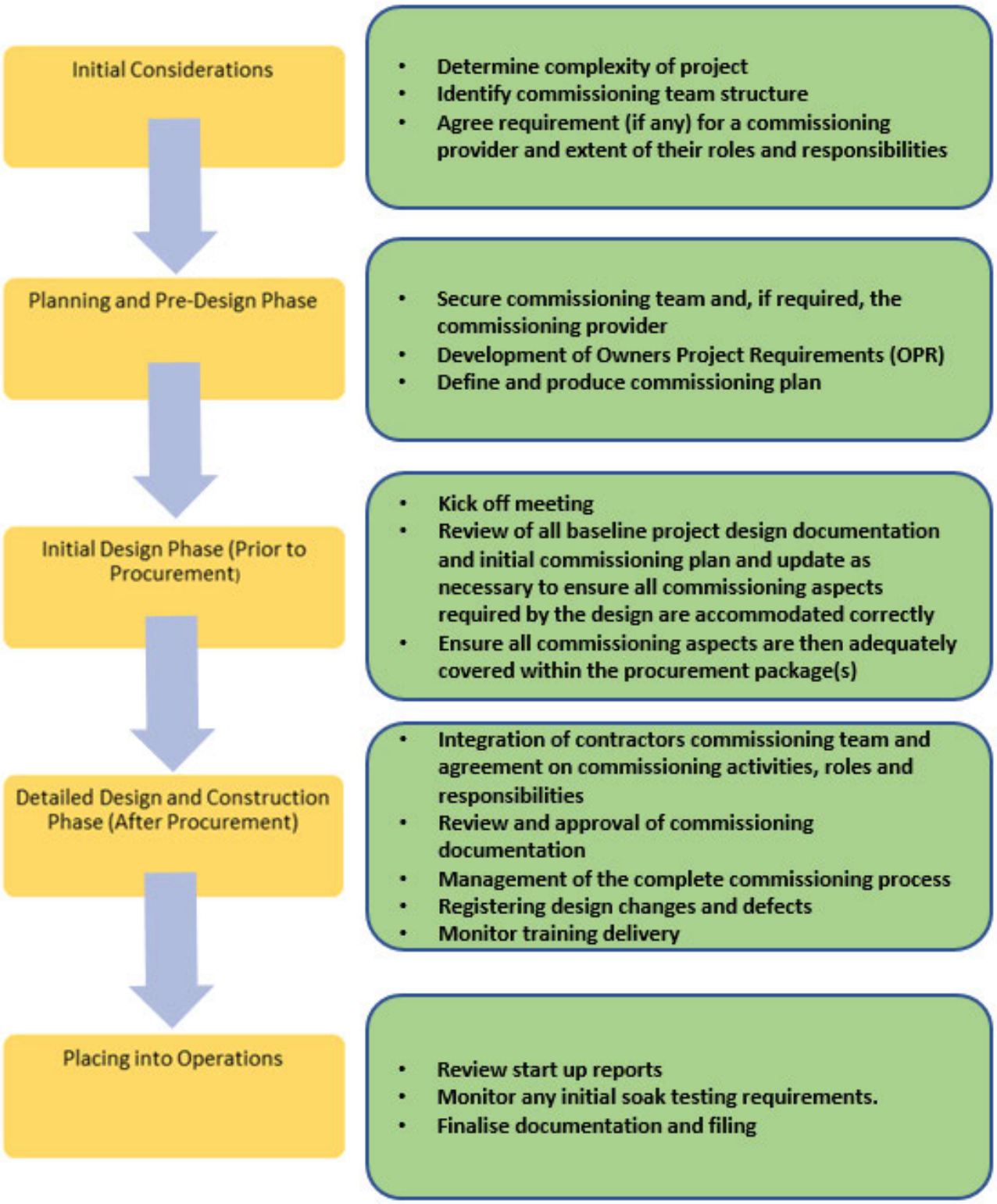

Figure 3-1. Commissioning Activities throughout the project delivery

[redacted]

- Determine complexity of project
- Identify commissioning team structure
- Agree requirement (if any) for a commissioning provider and extent of their roles and responsibilities

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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- [redacted]
- [redacted]

[redacted]

3.3 Planning and Pre-Design Phase

Figure 3-3.

Commissioning should begin in the planning and pre-design phase as this will then lay the foundations for the project and define the plan for commissioning.

During this phase the commissioning team should be identified and assembled, and a comprehensive suite of Owners Project Requirements (OPR) be developed [redacted].

The OPR will define the complete envelope of project requirements, from a technical, regulatory, commercial, and scheduling viewpoint. It will define the goals, benchmarks and success criteria for the project.

If the commissioning provider is tasked to assist during this initial project stage, then he will be expected to contribute towards the OPR by preparing a commissioning plan which will:

- Identify and agree [redacted] the Quality Management System (QMS) required to be used throughout the entire lifecycle of the project
- Address in detail how the development and ongoing management of the OPR, together with the initial Basis of Design (BOD) documentation, will be accomplished
- Define the approved processes for management of the design review process
- Identify the systems to be commissioned
- Identify the extent and type of commissioning documentation requirements
- Define the scope of the commissioning process and level/extent of commissioning activities required for all individual equipment and systems, along with the requirements for system integration commissioning.
- Define commissioning roles and lines of communications for each member of the project team
- Estimate the commissioning schedule
- Detail the budget required to manage the entire commissioning activity
- Prepare a suitable project issue log to capture defects/issues throughout the entire project life cycle

The level of detail required in the commissioning plan will naturally depend upon the complexity of the project and on who may be tasked to be the commissioning provider.

The commissioning plan should be updated at each formal step of design and at the start of construction.

If a commissioning provider is not engaged for this initial project phase, then the above activities should still be progressed by appropriately qualified staff [redacted].

[redacted]

3.4 Initial Design Phase (Prior to Procurement)

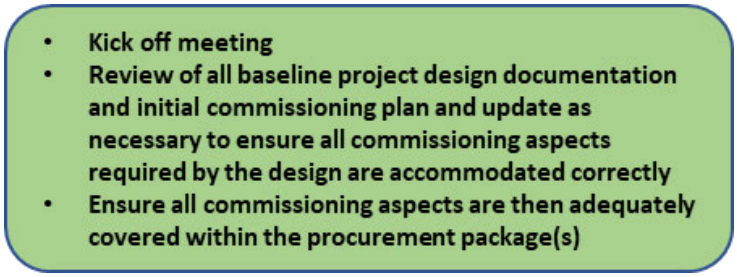

Figure 3-4

During the design phase, the main commissioning process activity is to confirm that design documentation (plans, specifications, Basis of Design (BOD), etc.) are consistent with each other, include and adequately address all commissioning requirements and meet [redacted] project requirements (e.g. the OPR).

The first activity during this phase should be for the complete commissioning team to assemble for a "commissioning kick-off meeting".

This kick-off meeting will seek to address the following topics:

- Review the project baseline documentation (OPR, BOD etc) to verify accuracy and consistency, including that the project commissioning requirements (including all aspects associated with testing, such as training and O&M documentation) meet [redacted] requirements.
- Ensure that the commissioning plan is consistent with the design specifications.
- Identify any [redacted] approved changes made since the pre-design phase that need to be captured.
- Verification that the test requirements are clearly defined and correctly reflect the system design. It should be noted that this may require a more in-depth review of equipment should, (for example) equipment configurations, settings, or system sequences of operation need to be defined and form part of any specific commissioning process.

Once completed, the approved OPR should then be used to develop the overall project design. This could be, for relatively simple projects, a suite of functional and performance technical specifications for the equipment/systems to be procured and placed into operational service.

For more complex projects, more detailed Design Intent Documentation (DID) may be required to replace and/or complement the functional and performance technical specifications.

The performance requirements specified will then become the acceptance criteria against which the systems will be assessed during the final commissioning process.

It is entirely possible that different design and procurement packages may be required for separate system elements if the concept of a main contractor undertaking all works under a turnkey contract is not appropriate. Under such circumstances, the responsibility for overall commissioning will need to be clearly identified, assigned and specified within the project and contract documentation.

In any event, the extent of commissioning required should be assessed by the commissioning provider during this project phase to ensure due consideration is given to the above aspects.

Upon completion of the above tasks the procurement process can commence.

3.5 Detailed Design and Construction Phase (After Procurement)

Figure 3-5

Following successful procurement and contact award to the contractor(s), the project construction phase can commence.

During this phase, the commissioning team shall work to ensure that equipment and systems are delivered to site without any defects, properly installed, integrated, commissioned and left in a manner which meets the Project Requirements (OPR).

At this time, the commissioning provider should be tasked to facilitate activities such as those described below:

- Review and update (as necessary) the commissioning plan developed during the design phase to integrate the contractor(s). This may include, for example, more detail about the project schedule, responsibilities, new project team members and communication protocols.
- Schedule a kick-off meeting with the contractor(s) to review the commissioning plan and ensure his duties and responsibilities are clearly understood and that appropriate resources are available to undertake the extent of works required.
- Schedule and coordinate integration meetings between the various design parties prior to formal design documents being submitted. This will assist in identifying interfacing issues which need to be addressed and requirements for commissioning. For example, if automation/control systems comprise part of the project then review of the design and commissioning of the control logic, sequences of operation and integration issues associated with the systems they are tasked to monitor, and control will need specific attention.
- Review and approve all test and commissioning specifications, procedures, plans and defect recording process
- Identify and agree the commissioning activity responsibilities required from all Parties.
- Manage and witness the Factory Acceptance Testing (FAT) activities
- Manage, witness and document the entire site commissioning process, including Site Acceptance Testing (SAT), performance testing and integrated system soak tests (noting that these may extend over long periods of time).
- Maintain a concise database holding details for all equipment and systems installed and commissioned (The Commissioning File).
- Review and confirm all commissioning activities have concluded satisfactorily and that the equipment and systems can be placed into operational service.
- Review the training requirements that were defined during the pre-design phase (e.g. overview and specific training on the equipment features, operation, safety, maintenance, alarms, and troubleshooting) and identify any changes. Develop detailed training agendas and identify the

appropriate [redacted] who will need to be trained to commission, operate and maintain the systems.

- Verify that all training is completed in accordance with the approved project documentation and [redacted] requirements and identify and schedule any follow-up training for staff that may be required.
- Review the contractors As-Built (ASB) and Operation and Maintenance (O&M) documentation.
- Prepare a comprehensive construction phase commissioning report [redacted]. This report should describe all equipment and systems installed and commissioned, the nature of commissioning and tests undertaken, the defects recorded and how they have been rectified, together with the integrated system performance testing results.

3.6 Placing into Operations

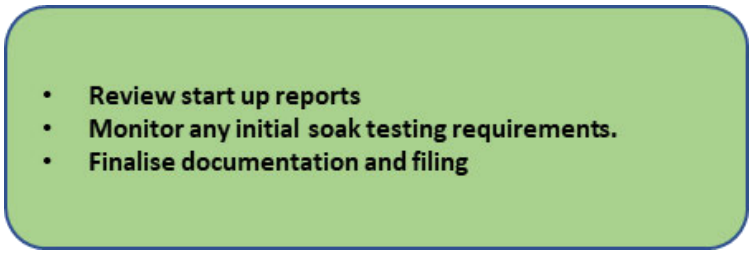

Figure 3-6

During this final project phase, the commissioning provider shall undertake the following tasks:

- Review the Contractors start-up and placing into operational service reports.
- Manage and report upon any long-term operational soak testing (for example, analysis and reporting of why any equipment settings and parameters set during design/installation and commissioning phases may have required adjustments post commissioning).
- Report back [redacted] with any required updates to the installation and O&M documentation
- Updates to reflect the final as-installed condition and closure of the project OPR document

3.7 Summary of Best Practice Commissioning Process

From the previous sections we can summarise the international best practice for commissioning of equipment and systems over the complete life cycle of a project as follows:

- Determine the requirements for commissioning and the required team at the initial stage of any project planning. This should include engaging a commissioning provider if appropriate.
- Finalise a comprehensive OPR document
- Finalise a QMS to address all commissioning activities
- Finalise a comprehensive commissioning plan
- Prior to procurement, ensure consistency between all design documentation and that all equipment and system interfaces are clearly and correctly defined with appropriate commissioning activities specified
- Engage with Contractor(s), integrate them into the commissioning team and agree roles and responsibilities
- Conclude a robust suite of integrated commissioning documents ensuring that all inter-related equipment and systems are fully exercised/tested

- Manage all commissioning test verification, defect resolution and clearance
- Ensure all reporting is completed timely and adequately
- Finalise all training and agree any follow-up (refresher) training as may be required to provide [redacted] assurance [redacted] assigned staff are capable of operating and maintaining the equipment and systems.
- Finalise all documentation, including O&M and ASB.

4 Application to the Findings of the NPS Issue

4.1 Introduction

Following a power system incident that occurred on the 18th December 2020, which resulted in an island-wide power outage, [redacted] was tasked to independently evaluate selected documentation to verify if it was able to provide any indications of what may have contributed towards the incident.

[redacted]

[redacted]

The following section details each finding in turn and discusses how the application of the commissioning best practices detailed in section 3 may have assisted with the prevention of the blackout.

4.2 Incident Analysis and Best Practice Applications

4.2.1 General Management of OPR Throughout the Project Life Cycle

The review identified that the initial functional specification as developed prior to tendering contained certain functionality for the [redacted] systems.

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4.2.5 Commissioning Documentation (SAT) Inconsistencies

The documentation reviewed suggests that:

- All functional tests have been undertaken and that no errors have been observed.
- All configurable settings have been verified/tested (where appropriate) and set correctly

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.2.8 Training Issues

A training schedule identifying that a series of training courses covering power plant and control system operations was provided, along with a document which was assumed to form the basic agenda for such training.

[redacted]

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