[redacted]

18th December 2020 Black out Review

Report for the Regulatory Authority of Bermuda

CONFIDENTIAL VERSION

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Revision history

Revision	Date	Author	Reviewer	Details
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Acronyms

AC	Alternating Current
BELCO	The Bermudan Electric Light Company
BWSC	Burmeister & Wain Scandinavian Contractor
CB	Circuit Breaker
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
MAN	MAN Energy Solutions
[redacted]	[redacted]
NPS	North Power Station
RA	The Regulatory Authority
[redacted]	[redacted]
[redacted]	[redacted]
SEL	Schweitzer Engineering Laboratories
[redacted]	[redacted]
[redacted]	[redacted]

1 Introduction

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 first of 2 reports examining the incident.

The purpose of this first report is to:

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

[redacted]

2 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 the [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] the [redacted] present at North Power Station.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4 BELCO Review of incident and findings

4.1 Overview of conclusions

The BELCO reports reach the following conclusions as to the Root Cause of the incident:

- **Functional failure of the bypass function [redacted]:**

This is described as a functional failure of the [redacted], as its operation caused high circulating currents between [redacted], and ultimately the tripping of the associated Circuit Breakers which interrupted control system supplies. This issue is explained in the Final report as being attributed to two factors:

1. A failure of the [redacted] whilst the transfer switch is in the "Interim" position, causing circulating currents between [redacted]; and
2. The Circuit Breaker settings being at the factory settings of [redacted] and not the settings recommended for the installation. The correct settings are not detailed in the reports [redacted].

- **The [redacted] configuration was incorrectly installed according to the contract specifications:**

During the incident investigation BELCO found that, contrary to their expectation and the Single Line Diagram provided for the system, [redacted] were not exactly the same. In particular the lack of [redacted] is mentioned.

Though the lack of this [redacted] not thought to have directly caused the incident, it does indicate failings in the Design and Commissioning process, such that BELCO were operating an electrical system without an accurate schematic.

- **Incorrect operating instructions mounted on the [redacted] control panel:**

Associated with the functional failure of the [redacted] described above, the operating instructions attached to the [redacted] A describing how to [redacted] were followed and did not deliver a controlled transfer of demand [redacted]. It is not clear from the reports whether the instructions are suitable with the rectification of the [redacted] issues identified above.

- **Failure to conduct commissioning and testing of the [redacted] in accordance with the Contract:**

The above issues indicate that commissioning of the [redacted] had not been properly performed. [redacted]

4.2 Additional control system issue

The BELCO Final Report also describes a problem detected during the subsequent investigation, with the Engine control system. [redacted]

Whilst it does not appear that this issue had any tangible impact on the outage, it did cause some confusion during the investigation. Meaningful and correct Alarm legends are important in both real time, so that operators are receiving accurate information about system conditions, and also after an event for review purposes.

4.3 Incident Investigation

From the accounts of the investigation described in the reports it appears that considerable effort have already been expended to in investigating the incident. Representatives from BELCO, BWSC (the [redacted] supplier) and MAN (The engine supplier) have all been contributed to the investigation, and 36 tests conducted on the [redacted] system.

5 Review of additional information provided by BELCO

In response to a request from REE, the RA has provided us with the additional following information, all of which has been reviewed whilst preparing this report.

Requested Document	[redacted]	[redacted]
Employers Requirements document:	[redacted]	[redacted]
The contractors' [redacted] functional design specifications	[redacted]	[redacted]
Contractors' [redacted] functional design specifications	[redacted]	[redacted]
The FAT and SAT/commissioning procedure documents for [redacted] (including the signed off documentation as completed)	[redacted]	[redacted]
SLD of the installation	[redacted]	
Timeline of system events from the control system	[redacted]	[redacted]
Information on the training delivered prior to commissioning.	[redacted]	[redacted]

Table 5-1. Summary of Supplied information.

The following describes the material provided, and REE's observations on the material.

5.1 Employers Requirements

A functional specification and indicative [redacted] were provided, it is assumed that these were the documents used during procurement. The documents describe the required functionality and provide an [redacted] of a suitable design, with the requirement that it should comply with [redacted] and [redacted].

The documents provide a description of the hardware requirements for the [redacted] system. It also details some specific functionality that the system should include.

[redacted]

Figure 5-1. [redacted] Functional requirements

[redacted] It is therefore not possible to comment on the extent to which a clear delineation of roles and responsibilities for the various hardware systems was made, scope of supply boundaries, documentation requirements, any procedural requirements for Design and Commissioning (e.g. test witnessing) etc. It is also not possible to know if any deviations from the specification were agreed.

5.2 Contractors [redacted] Functional Design Specification

BWSCs specification has been provided, describing the hardware being provided, [redacted]

[redacted]

Section 8 details the requirements for Factory Acceptance Testing, including the test themselves. The tests listed are all concerned with [redacted]

[redacted]

[redacted]

[redacted] [redacted]

5.3 Contractors switchgear Functional Design Specification

[redacted] There is a statement that a [redacted] shall be provided to enable isolation of the [redacted].

5.4 The FAT and SAT/commissioning procedure documents

Three documents have been provided:

- [redacted]
- [redacted]
- [redacted]

These are discussed in more detail in Sections 5.4.1, 5.4.2 and 5.4.3 below:

5.4.1 The [redacted] Factory Test Report

The panel was supplied by [redacted] to BWSC.

The report details the results of testing following the [redacted] build. It includes checks that the [redacted] has been built in accordance with the design and appropriate standards. It is not clear from the document if the [redacted] tested is the [redacted], or the [redacted], or both, as the cover sheet is incomplete, and does not specify. No date is given on the document.

Of note in the test are rows:

- [redacted] Which are concerned with testing/checking of [redacted], all of which are marked "Not Applicable". This could be because these were to be added to the board at a later date.
- [redacted] "Check control circuits referring to drawings and documentation" which is marked "OK".
- [redacted] Are concerned with the layout being as specified and are marked "OK".

As previously mentioned, it is not clear exactly what was tested at this point, so it is difficult to draw too many conclusions. One possible explanation is that this document refers to a test of the switchboard(s) in a state of basic assembly, with connections to other equipment [redacted] and the addition of [redacted] to be added at a later date.

[redacted] [redacted] Factory Test Report [redacted]

These [redacted] factory tests were completed on 17th April 2019, by personnel from both [redacted] Conclusion from these UPS factory tests was that the equipment could be released for delivery, having been "accepted with reservations".

The reservations are listed [redacted] and include what [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

These deficiencies are marked as being rectified on 26th April 19. Without more detailed diagrams of the equipment and the changes made, it is not possible to understand exactly what changes were made, and the design documentation basis used.

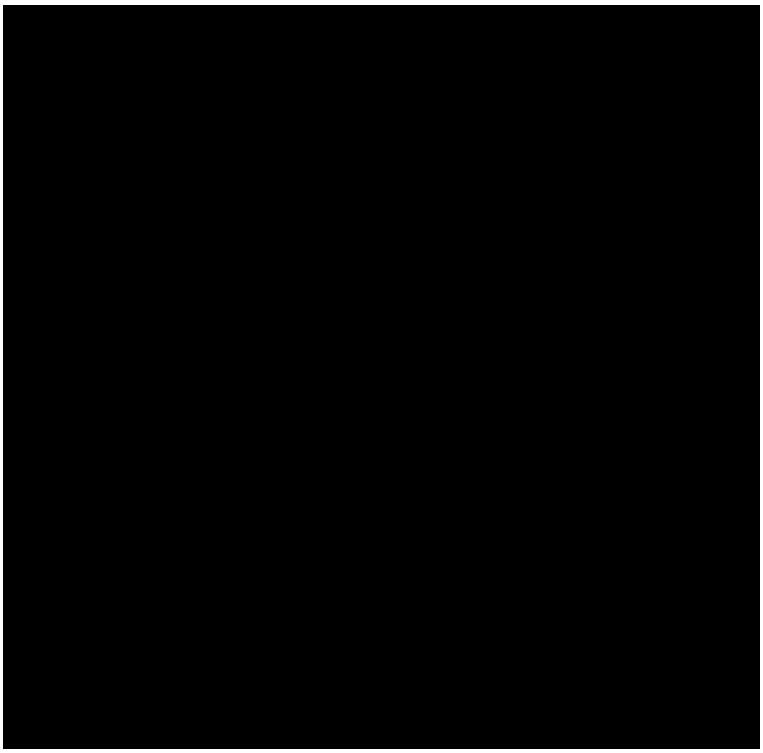
Tests [redacted] indicate that components and mimics were at this point in accordance with drawings.

Tests [redacted] indicate that the functional performance of the equipment was tested in accordance with the drawings and specification. There are several explanations for how these tests were signed off as being satisfactorily performed without highlighting the issues encountered [redacted]
Tests could have been performed:

- in accordance with an incorrect or incomplete set of documentation [redacted]
- on a limited set of hardware [redacted]
- On equipment that performed differently at this stage than it did on the 18th of December 2020, as it was configured or installed differently.

[redacted] Test & Commissioning Test Report [redacted]

[redacted]



[redacted]

Records of site tests performed between 4th January 20 and 17th January 20 were provided. These relate to the whole [redacted].

Several tests that are checked as “OK” should’ve provided the opportunity to rectify problems that became apparent on the 18th of December 2020. In particular line [redacted] commissioning checklist states [redacted] which should’ve highlighted the issue raised in section 4.2. A further test in the [redacted] should also have found this error.

[redacted]

[redacted]

[redacted]

Figure 5-3. Extracts from commissioning test record for [redacted] I/O tests

[redacted] The subsequent investigation found that these were set at [redacted] and not the required setting in excess of [redacted] Interestingly line 12 also requires settings to be adjusted in accordance with design set points but requires the commissioning engineer to note the required settings. This ensures that the engineer checks the design document and notates the correct settings. The [redacted] settings check in Line 9 just requires a tick.

[redacted]

Figure 5-4. Extracts from commissioning sheets, showing different notation for under/over voltage devices and MCB.

Notably line 17 requires [redacted], and again is marked as “Okay”. As noted in section 3, issues with [redacted] has been identified by BELCO as creating high circulating currents which caused breakers to trip.

Also pertinent are several items that are not included in the test sheets, that would be according to international best practice:

- Confirmation that the installation has been carried out and checked against the specified design;
- Settings sheets for devices [redacted]
- Confirmation that schematic/wiring diagrams have been checked and marked up and any issues resolved.

  Functional testing to demonstrate all of the required functions as captured in the employer’s requirements (Those captured in Figure 5-1 [redacted] Functional requirements).

5.5 Single Line Diagram of the installation

Two SLDs of the installation were provided.

The first (Version 3) is from 09th October 2020 and is a “General Update” to an “As Built” Diagram issued on 05th August 2020. This diagram shows [redacted] and doesn’t note any communications between the [redacted] for [redacted] purposes.

The second diagram (Version 4) is also a “General Update” issued on 07th January 2021. This diagram removes the [redacted] from [redacted] and indicates the [redacted] communication path between the [redacted].

The use of term “General Update” in the title block for these diagrams is not overly helpful for owners and operators, and more specific descriptions of diagram changes are preferred. This is particularly the case if changes to the system configuration have been made that could have implications on operations and safety.

5.6 Timeline of the event

A log of control system data was provided in an Excel spreadsheet format, and provides data from the 18th of December from a number of sites.

It is of limited use in determining the sequence of events. It does indicate that at the time of the event, switches at SSB NORTH, SSB SOUTH and NPS all tripped. Note that the nomenclature of the alarm labels is not consistent.

Time	St Desc	Pt Desc	Status Pair
12/18/2020 10:15:44:750	SSB NORTH	[redacted]	**** TRIPPED ***
12/18/2020 10:15:44:756	SSB NORTH	[redacted]	**** TRIPPED ***
12/18/2020 10:15:44:993	SSB SOUTH	[redacted]	**** TRIPPED ***
12/18/2020 10:15:44:999	SSB SOUTH	[redacted]	**** TRIPPED ***
12/18/2020 10:15:47:231	NPS	[redacted]	**** TRIPPED ***
12/18/2020 10:15:44:892	NPS	[redacted]	**** TRIPPED ***
12/18/2020 10:15:45:136	NPS	[redacted]	**** TRIPPED ***
12/18/2020 10:15:46:334	NPS	[redacted]	**** TRIPPED ***
12/18/2020 10:15:45:341	NPS	[redacted]	**** TRIPPED ***

Figure 5-5. Tripping information at 10.15 on 18th December 2020

The log does not provide information on the tripping at the East Power Station or the Battery Energy Storage System. The format of the date for the alarms is not consistent, and alarms appear out of sequence, though it is not possible to say if this is as recorded in the control system, or as a result of the data export into Excel.

Time	St Desc	Pt Desc	Status Pair
18/12/2020 10:17	NPS	[redacted]	NOT AVAILABLE
18/12/2020 10:17	NPS	[redacted]	NOT AVAILABLE
18/12/2020 10:17	NPS	[redacted]	NOT AVAILABLE

Time	St Desc	Pt Desc	Status Pair
12/18/2020 14:18:07:546	NPS	[redacted]	NORMAL
12/18/2020 14:18:07:949	NPS	[redacted]	NORMAL
12/18/2020 10:15:40:827	NPS	[redacted]	ALARM
12/18/2020 10:15:40:827	NPS	[redacted]	OPERATED
12/18/2020 10:18:04:552	NPS	[redacted]	NORMAL
12/18/2020 10:18:04:552	NPS	[redacted]	NORMAL
12/18/2020 10:15:40:894	NPS	[redacted]	ALARM
12/18/2020 10:15:40:941	NPS	[redacted]	ALARM
12/18/2020 10:15:45:083	NPS	[redacted]	OPERATED
12/18/2020 10:15:45:136	NPS	[redacted]	**** TRIPPED ***
12/18/2020 10:18:04:828	NPS	[redacted]	NORMAL
12/18/2020 10:15:41:266	NPS	[redacted]	ALARM

Figure 5-6. Examples of inconsistency in date format and alarm sequence

A log from the Generator protection relays (Differential relays type SEL-700G) downloaded on the 30th of December 2020, showing the events from 10.15am on the 18th December 2020 was also provided.

Of note in this document is that Generators N1, N3 and N4 all record a “Trip from Governor”, with Unit N4 recording this first at 10:15:44.938, N1 at 10:15:45.594 and N3 at 10:15:45.787. A trip of this type would be expected following a loss of the engine control system.

Unit N2 trips on Underfrequency at 10:15:46.110, after the breakers on the other units are recorded as being open.

This difference is likely due to slight differences in wiring distances, relay operating times, relay clocks etc. such that Unit N2 would also have been tripped from the Governor as per the other units, but the Underfrequency element operated first. However, it should be checked that Unit N2 does have the same tripping initiation for a loss of the control circuit supply.

It is also noted that for all units the CB fail timer is reset approx. 50mS prior to the CB being recorded as being open. Once again this is most likely due to small timing errors rather than any error in the CB fail scheme logic, but once again this should be confirmed by verification of the CB fail scheme.

5.7 Information on the training delivered prior to commissioning

A training log of courses delivered to staff between January and April 2020 was provided, together with slides showing single line diagrams of the electrical systems and details of the LV control system data. It is

not clear from the material the extent to which understanding of the [redacted] and its operation was disseminated.

6 Conclusion

6.1 Causes to the 18th December 2020

This document has reviewed the 3 incident reports issued by BELCO, together with supplementary information, regarding the island wide blackout that occurred on 18th December 2020.

The incident itself appears to have been caused by the issues identified by BELCO, specifically:

1. A failure of the [redacted] system between the [redacted] whilst [redacted], causing circulating currents [redacted]: and
2. The Circuit Breaker settings being at the factory settings of [redacted] and not the settings recommended for the installation. The correct settings are not detailed in the reports, [redacted].

Both of these issues should have been detected prior to completion of the commissioning process.

6.2 Other Findings

Other than the cause of the incident, several other indicators of practice below the expected standard were found.

The BELCO incident investigation reports include:

- **The [redacted] configuration was incorrectly installed** [redacted] In particular no [redacted] was provided on [redacted]. Review and acceptance of a contractor's design, and confirmation that the installation was in accordance with that design should be obtained prior to commissioning.
- **Alarm Nomenclature was found to be inaccurate in the engine control system**, displaying "Engine Stop due to Engine room Ventilation failure/Gas Alarm" instead of a legend associated with the [redacted] A process that assures accurate end-to-end commissioning of the installed systems is required.

The most significant aspects from the [redacted] review are:

- **Unclear delineation of the commissioning process requirements**, so that the testing sequence did not ensure that all elements were proven. The documentation provided gives the impression of a desperate series of tests, with no clear strategy to ensure a fully working system was delivered. Good commissioning practice typically includes:
    - client witnessing requirements and hold points to ensure that key aspects of testing are confirmed.
    - Coordination meetings to understand progress, dependencies and upcoming tests.

  If documentation to this effect does exist it was not provided.

- **The Site Commissioning tests did not include specific functional tests,** to ensure that the bespoke requirements of the contract were delivered [redacted].

- **The "As Built" SLD was found to be inaccurate;** and two subsequent revisions had been carried out and marked "General Update". At least one of which included substantive changes to the system configuration, not accurately captured by the term "General Update". The accuracy of other "As Built" diagrams associated with the project must also be in some doubt, particularly more complex wiring or schematic diagrams.

6.3 Preliminary views and next steps

This review has highlighted a number of deficiencies in the commissioning process. This process is 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.

The site commissioning tests did provide opportunity to identify the issues that caused the outage on 18th December 2020 [redacted]. However, the opportunity was missed, and latent defects were left in situ – leaving the North Power Station exposed to the risks [redacted].

As a result of the findings detailed in the BELCO incident reports and this report, [redacted].

[redacted]