THE BAHAMAS POWER SYSTEM STABILITY STUDY FOR THE IMPLEMENTATION OF A HIGHER RENEWABLE ENERGY PENETRATION LEVEL

REPORT ON THE ANALYSIS OF THE MEASURED DATA FOR ELEUTHERA AND EXUMA

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1 INTRODUCTION

This document describes the analysis of the measured data recorded in the electric power systems of the islands of Eleuthera and Exuma in the project *The Bahamas power system stability study for the implementation of a higher renewable energy penetration level* funded by United Nations Industrial Development Organization (UNIDO).

The purposes of this report are to:

- Provide an overview of the measurement data that could be obtained,
- Analyse the measured data with regard to the information that can be derived on the power systems of Eleuthera and Exuma.

The purpose of collecting and analyzing the measured data was originally to support the modeling prior to conducting the transient stability analysis. This objective could not be met as the measurement data has become available too late in the project, due to various delays with multiple causes, and as the finally obtained data remains incomplete.

Six measurement devices were prepared by Energynautics for the data collection, and shipped to The Bahamas for installation on the family islands of Eleuthera and Exuma. The installation was to be performed by a joint team of a local consultant hired for the purpose (Graphite Engineering) and Bahamas Power and Light Company Limited (BPL).

In addition to measurement data obtained from these devices, any data that could be collected from BPL's supervisory control and data acquisition (SCADA) system was also of interest as the six devices would not have been sufficient to measure the complete load demand on all feeders in the power systems.

2 COLLECTED DATA

A total of four files with measurement data could be obtained:

File	Description
Filename: enalogger01_2023-04-09_00-00-00.cea Received: 2023-May-08	Data collected by Energynautics measurement device on Eleuthera, Hatchet Bay Power Station, South Feeder, between 2023-Apr-09 and 2023-Apr-17
Filename: enalogger01_2023-04-16_00-00-00.cea Received: 2023-May-08	Data collected by Energynautics measurement device on Eleuthera, Hatchet Bay Power Station, South Feeder, between 2023-Apr-16 and 2023-Apr-24
Filename: Hatchet Bay Mar-May 2023 (kW, kVar).xlsx Received: 2023-May-22	Data collected from BPL's SCADA system on Eleuthera, Hatchet Bay Power Station, North Feeder and South Feeder, between 2023-Mar-01 and 2023-May-22
Filename: Exuma March 2023- Present (kW, kVar).xlsx Received: 2023-May-24	Data collected from BPL's SCADA system on Exuma, George Town Power Station, Generators 1-4, between 2023-Mar-01 and 2023-May-24

One additional file has also been obtained, but did not contain any data:
"North Feeder archive03_2023-03-18_23-00-00 -.cea", received 2023-Apr-28.

The data collected from Eleuthera contains data from two (i.e., both) feeders in Hatchet Bay Substation, but does not contain data from any of the other two power stations on Eleuthera (Rock Sound Power Station and Harbour Island Power Station).

The data from Exuma contains data from two generators (plus two others that were out of service during the entire measurement period), but does not give information on the distribution of load demand across the feeders and might also be incomplete due to the known presence of additional (rental) generators in Exuma.

The data collected from BPL's SCADA system contains active and reactive power in hourly resolution. The data collected from the Energynautics measurement devices contains a wide range of measurement signals (powers, voltages, currents, frequencies, etc.) in thirty-second resolution.

The data archives collected from the Energynautics measurement devices can be opened and inspected in the ENVIS software that can be downloaded for free from the 'Software' section at https://www.pq-plus.de/en/media-downloads/. The data have been exported to Excel format for further processing and analysis.

3 ANALYSIS OF DATA FROM ELEUTHERA

3.1 SCADA DATA FROM BPL

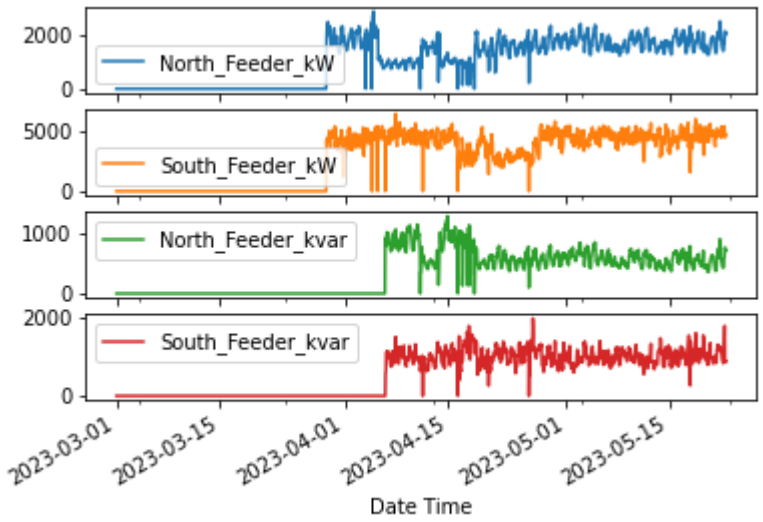

Figure 1: Plot of Hatchet Bay Feeders' SCADA Data

A plot of the SCADA data from the two Hatchet Bay feeders is shown in Figure 1. While the file contains measurement data in hourly resolution beginning on 2023-Mar-01, the first few weeks only values of zero kilowatt (active power) and kilovar (reactive power) are recorded. It is assumed that this does not reflect a prolonged outage in the power supply of the feeder, but instead an issue with the data recording, because the recording of data with more expected visualization profile starts at different times later for active power (end of March) and reactive power (later part of first week of April).

Typical values and fluctuation ranges can be read from the plot. No other signals beyond the ones plotted above are available in the data file.

3.2 DATA FROM ENERGYNAUTICS MEASUREMENT DEVICES

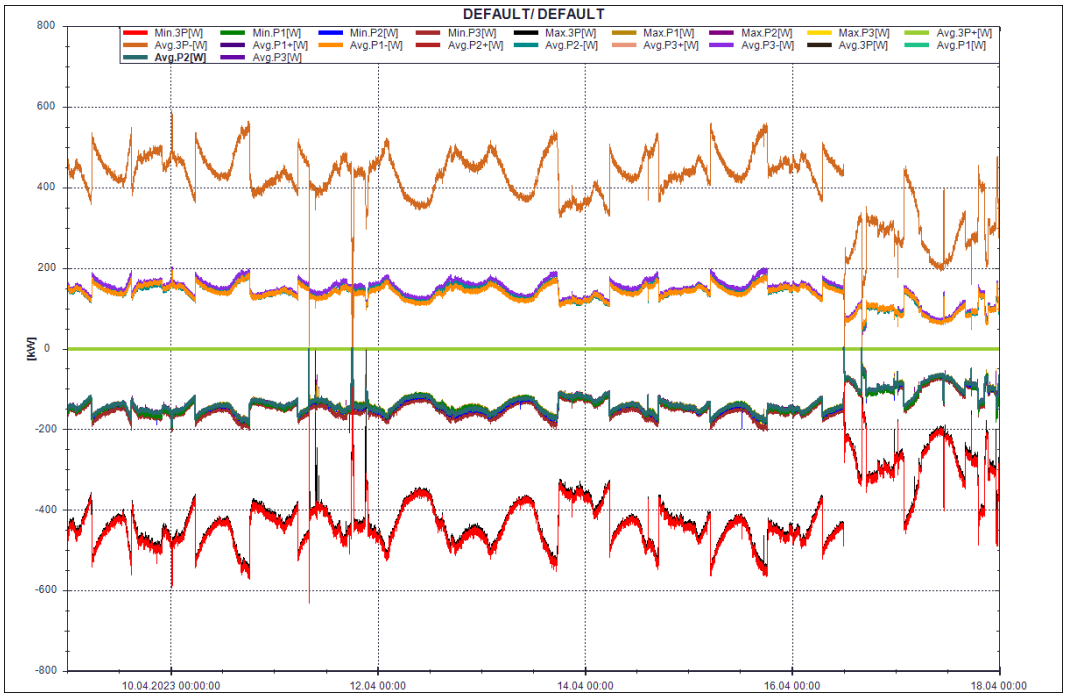

Figure 2: Active Power Signals Available in Measurement File

The data files obtained from the Energynautics measurement devices contain a multitude of signals. As an example, Figure 2 shows the available active power signals. Since we are only interested in the total active power (aggregation of all three phases), we choose the signal named "Avg.3P-[W]" for further evaluation (called "ENA_South_Feeder_kW" below).

Similar choices of extracting the most relevant signals are made for reactive power, voltage, and frequency. Figure 3 and Figure 4 show plots of these signals. The files contain data from a full calendar week (from Monday through Sunday) with one additional padding day before the beginning and after the end of the week.

Typical values and fluctuation ranges can also be read from these plots.

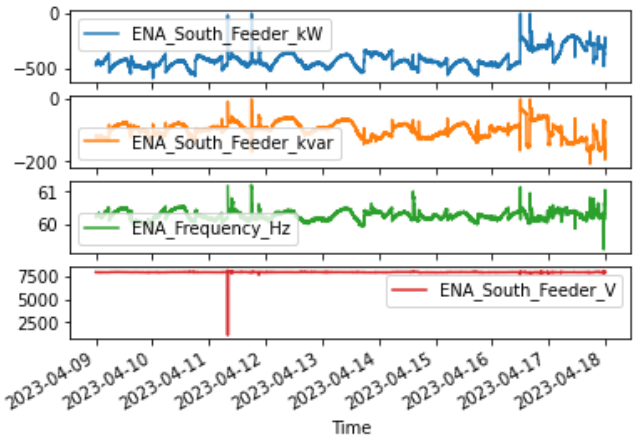

Figure 3: Plot of Selected Signals (first week)

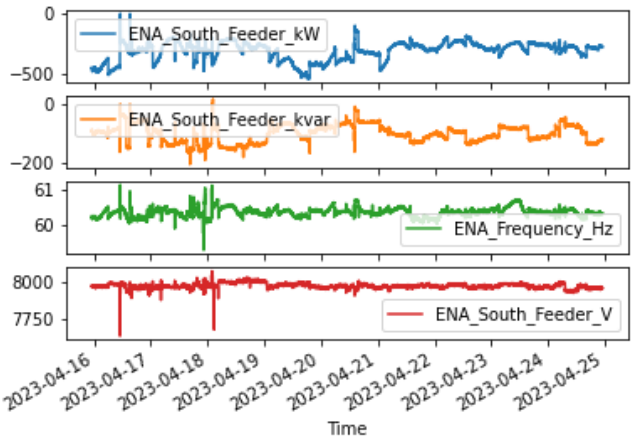

Figure 4: Plot of Selected Signals (second week)

3.3 CROSS-VALIDATION OF MEASURED DATA

The availability of three files with measurement data from the South Feeder at Hatchet Bay Power Station on Eleuthera with overlapping measurement periods allows a minimum of cross-checking between the recorded signals.

It turns out that the signals deviate in multiple ways:

The signs of recorded active and reactive power signals are inverted between the two data sources (BPL SCADA and Energynautics measurement device). We invert the Energynautics measurement device signal for further comparison.

The magnitude between the recorded active power signals differs by a factor of ten, with the magnitude recorded by the BPL SCADA system being the larger one. We assume that there was an incorrect calibration or configuration setting somewhere in the Energynautics measurement device and multiply its signal by ten for further comparison. The same is needed for the reactive power signal.

The overlapping time window of 16 and 17 April 2023 for the accordingly corrected signals is plotted below in Figure 5 and Figure 6.

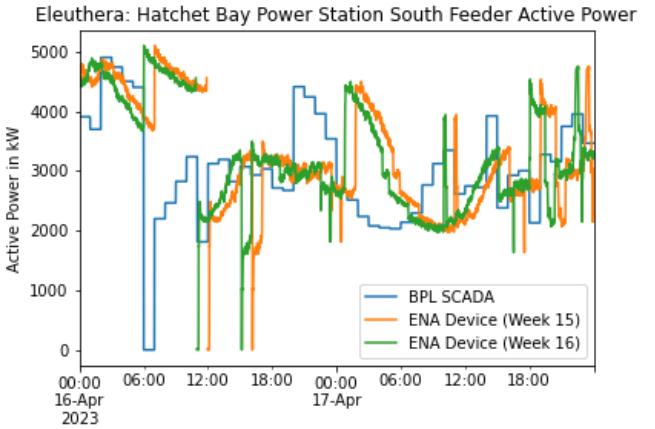

Figure 5: Active Power Signals on 16 and 17 April 2023

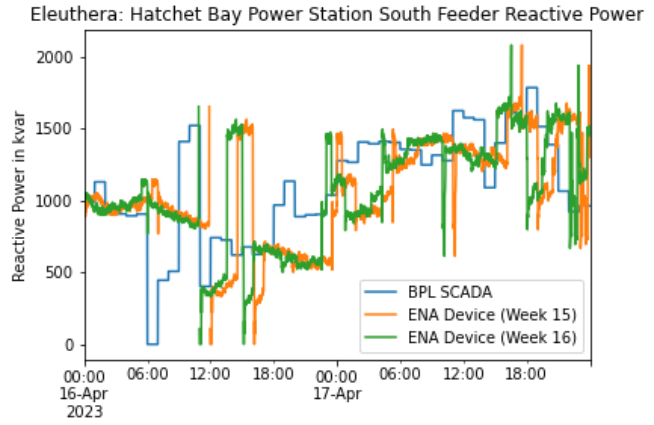

Figure 6: Reactive Power Signals on 16 and 17 April 2023

As can be observed from the plots, there is also a time offset between all three data files for Eleuthera, even between data from the same measurement device. The two files from the Energynautics measurement device appear to be off by something between one and two hours, with another 5-6 hour difference to the timestamps from the SCADA data.

A quick inspection of the two original files from the Energynautics measurement devices in the ENVIS software reveals that there is actually no time offset between the two corresponding recordings in the original data. Further analysis of the exported files reveals that the observed offset must have been introduced when exporting the data from ENVIS to Excel format. The most likely cause is a software bug in ENVIS.

The time offset of 5-6 hours between the SCADA data and the other files could be explained by the time configuration in the measurement devices. The Energynautics measurement devices were originally set up and tested by Energynautics in Germany, which is located in a time zone with 5-6 hours difference to the Bahamas (depending on the date and the respective switch days of the countries to daylight savings time). It is possible that the device installation team on the Bahamas did not configure the time zone setting in the devices.

3.4 DEMAND PATTERN IDENTIFICATION

In addition to typical values and variation ranges, knowing typical patterns (e.g., daily patterns) of the load demand is useful in order to forecast the loading of the grid equipment and identify critical situations. In particular daily patterns can be identified more easily in additional plots. We therefore plot the SCADA data (which covers the longest recording interval) as time-over-day-heatmap and as overlay of all daily plots in Figure 7 through Figure 10.

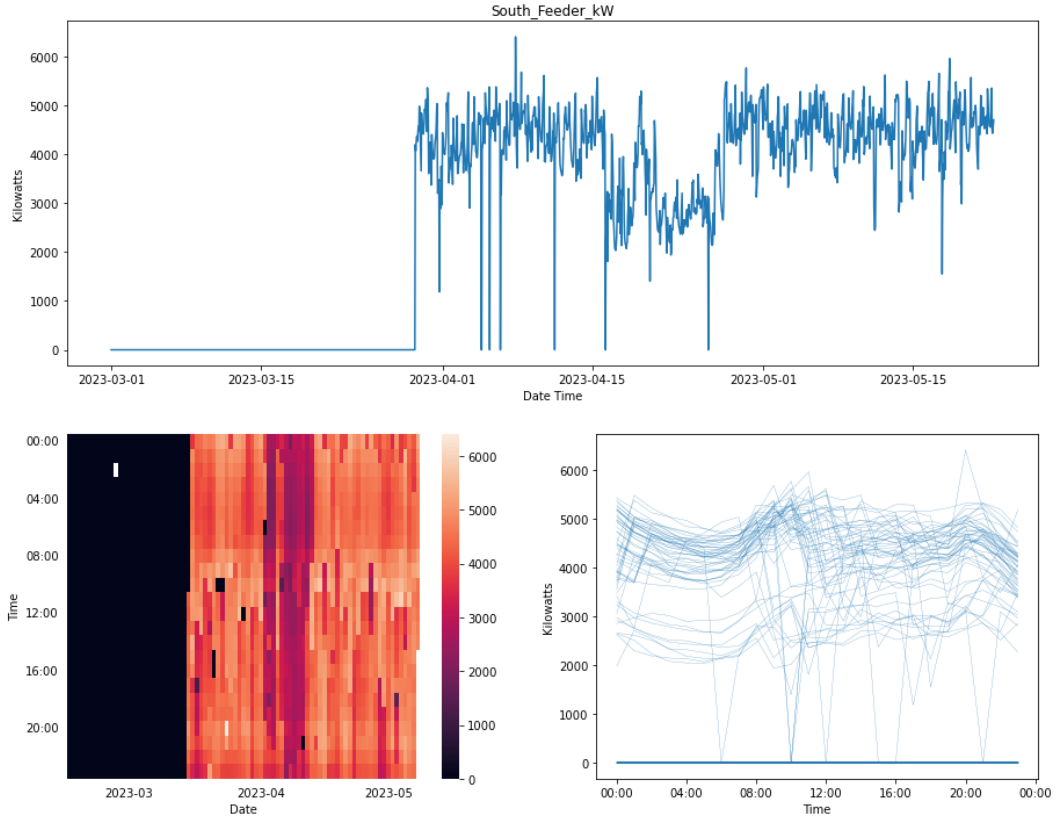

Figure 7: Three Plots of Hatchet Bay Power Station South Feeder Active Power

Looking at Figure 7 one can see that the load demand on the Hatchet Bay South Feeder typically varies between roughly 4 and 6 Megawatts. However, there is about one week in April 2023 (starting around 16 April) where the demand is decreased and varies mostly only between 2 and 4 Megawatts. The reason for this exceptional week is unclear so far; it does not coincide with any Easter holiday.

Something resembling a typical daily curve can be observed in the night time between 20:00h in the evening and 10:00h in the morning. In the daytime 10:00h and 20:00h there are fluctuations that prevent the identification of a typical daily demand curve. It is possible that embedded generation (e.g., with solar photovoltaics) plays a role in these fluctuations, but there may be other explanations pending discovery.

Short outages have occurred multiple times in the observed time interval of just a few weeks, indicating that reliability of the power supply to this feeder is limited. Outages tend to be more likely to be observed in the daytime compared to the nighttime.

Similar observations can be made looking at the reactive power at the same feeder (Figure 8) and at the North Feeder plots (Figure 9 and Figure 10).

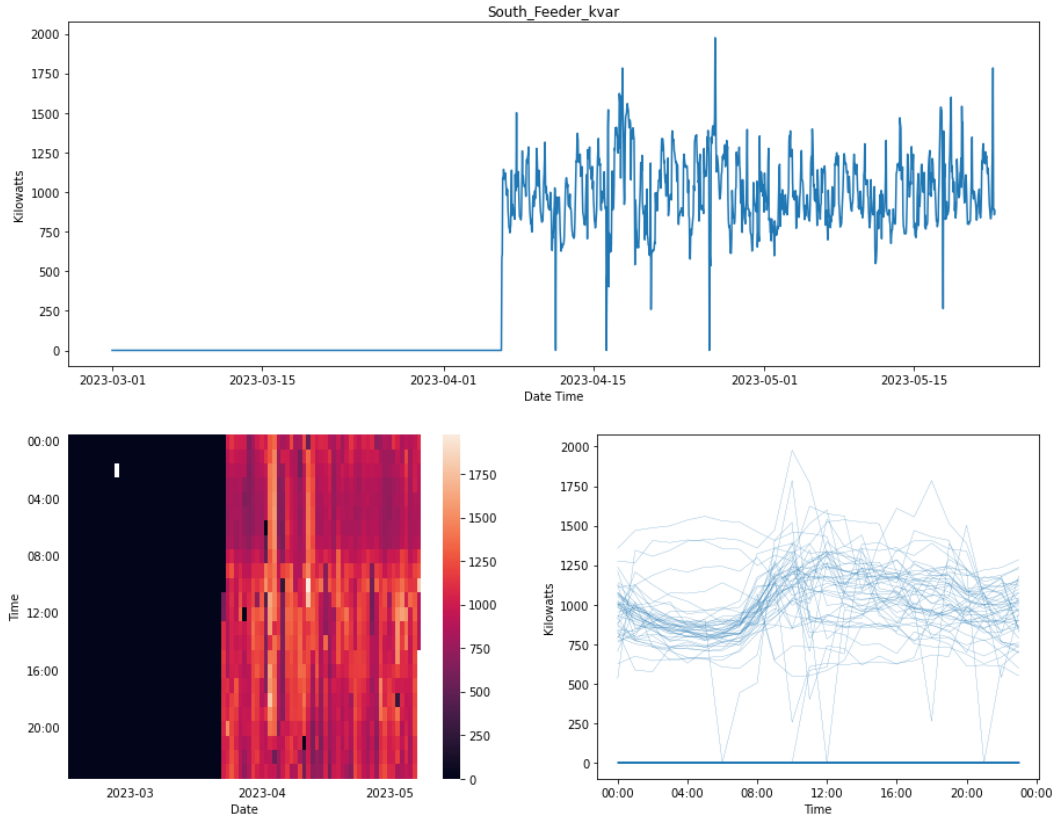

Figure 8: Three Plots of Hatchet Bay Power Station South Feeder Reactive Power

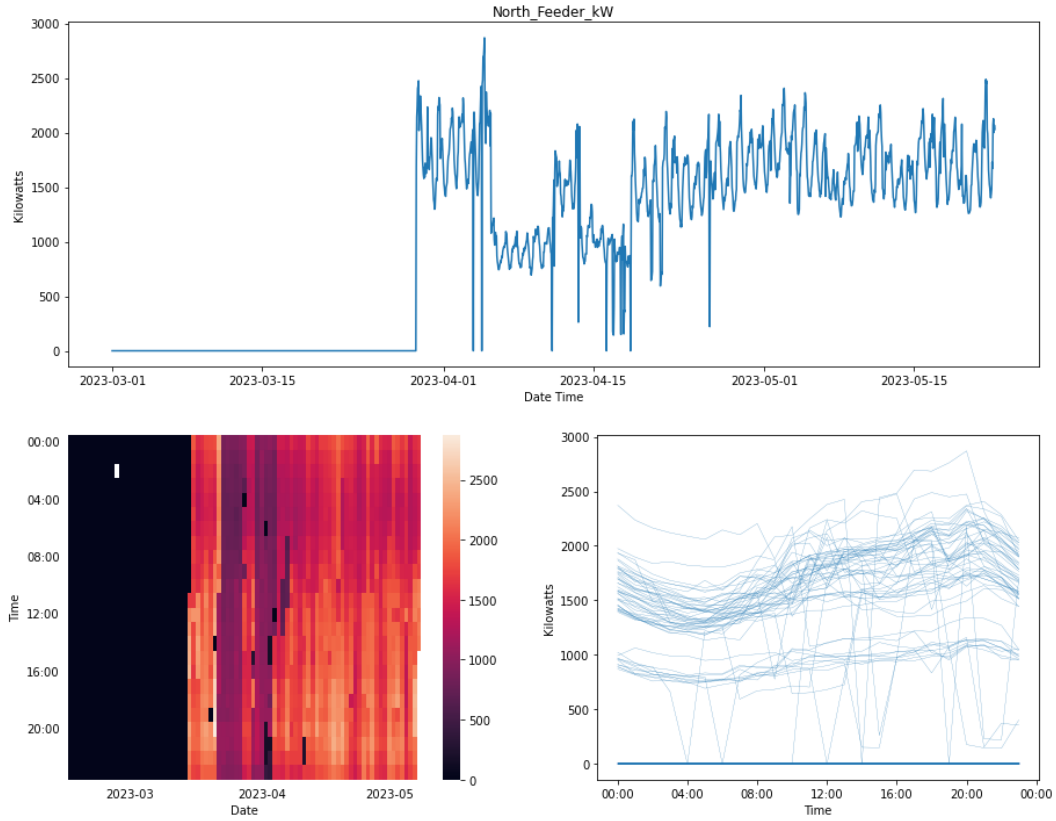

Figure 9: Three Plots of Hatchet Bay Power Station North Feeder Active Power

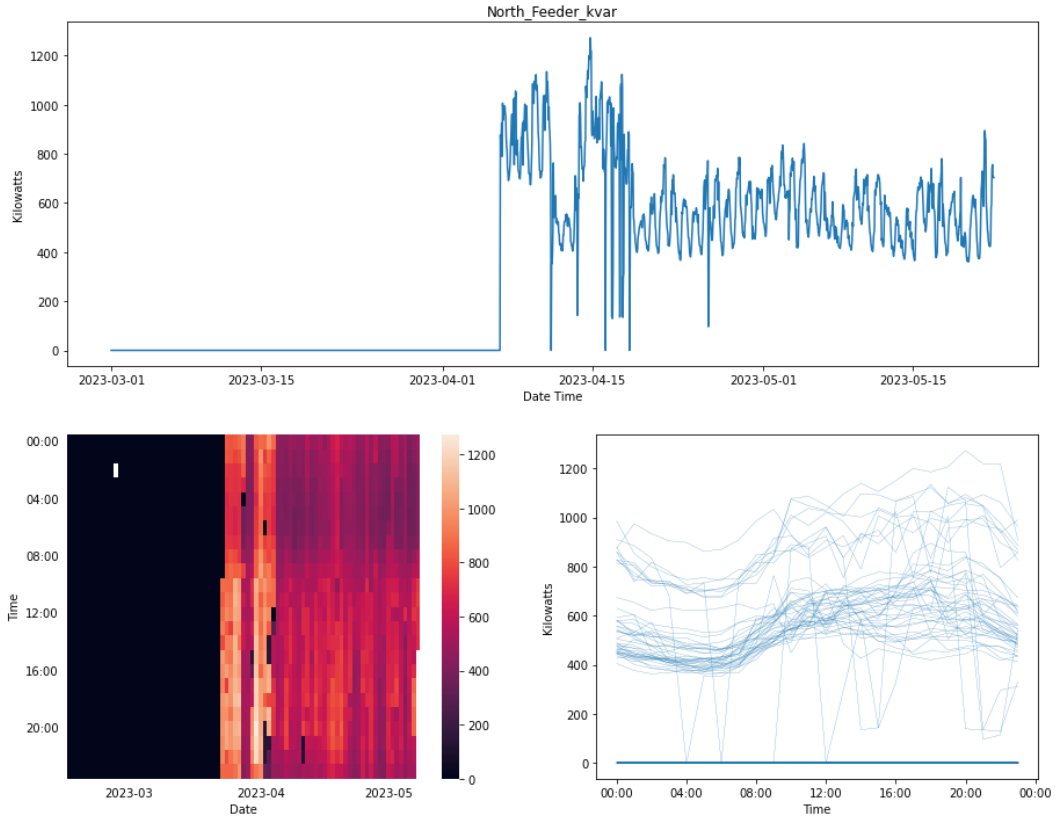

Figure 10: Three Plots of Hatchet Bay Power Station North Feeder Reactive Power

4 ANALYSIS OF DATA FROM EXUMA

The data from Exuma contains data from four generators. This data is plotted in Figure 11. As can be seen in the figure, generators “DG1” and “DG3” have been in operation during the observed time interval; the other generators “DG2” and “DG4” have been out of service.

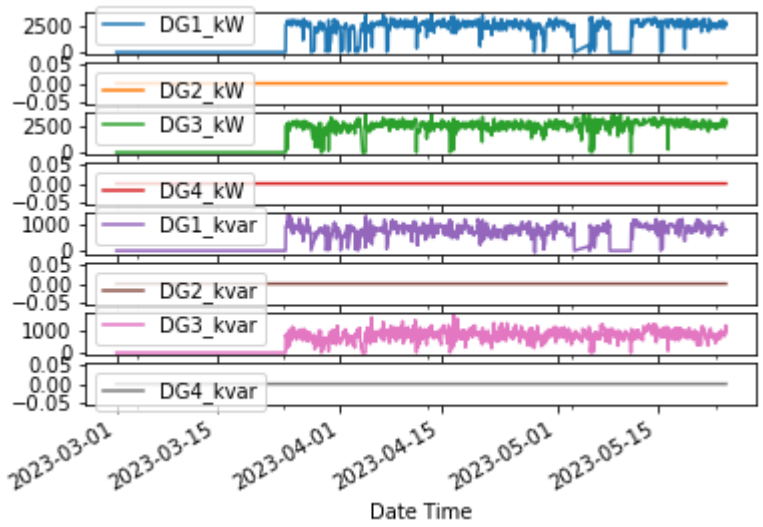

Figure 11: Plot of SCADA Data from Exuma

Similar to the SCADA data obtained from Eleuthera, there is an initial time period in the recording where all values are zero. Again it is assumed that this does not reflect a prolonged outage in the power supply of the feeder, but instead an issue with the data recording or with the extraction of the data from the SCADA system.

Since both active generators are connected to the same bus bar and the distribution of load demand across the feeders is not known, we aggregate the output of the generators to obtain the output of the entire power station. The aggregated data is plotted in the format suitable for pattern identification in Figure 12 and Figure 13.

The aggregated active power typically varies in the range between 4 and 6.5 Megawatts, but there are also time periods where the fluctuations are larger (last days of March and first days of April) or where the range of variability remains at a lower level between 2 and 4 Megawatts (some days in early May). The reasons for these changes of patterns are again not known to the consultants yet. Results for reactive power are qualitatively similar to the above description of active power.

Variations between different days are sufficient to prevent deriving a typical demand profile with good confidence. Recordings over a longer period and discussion of the observations with the operators would be useful to obtain better conclusions here.

For the interpretation of the data from Exuma it must also be noted that consultants have been informed by BPL about the presence of additional (rental) generators in Exuma. The output of these generators is not present in the measurement data that has been provided. The data might therefore be incomplete with regard to representing the complete demand profile of the island.

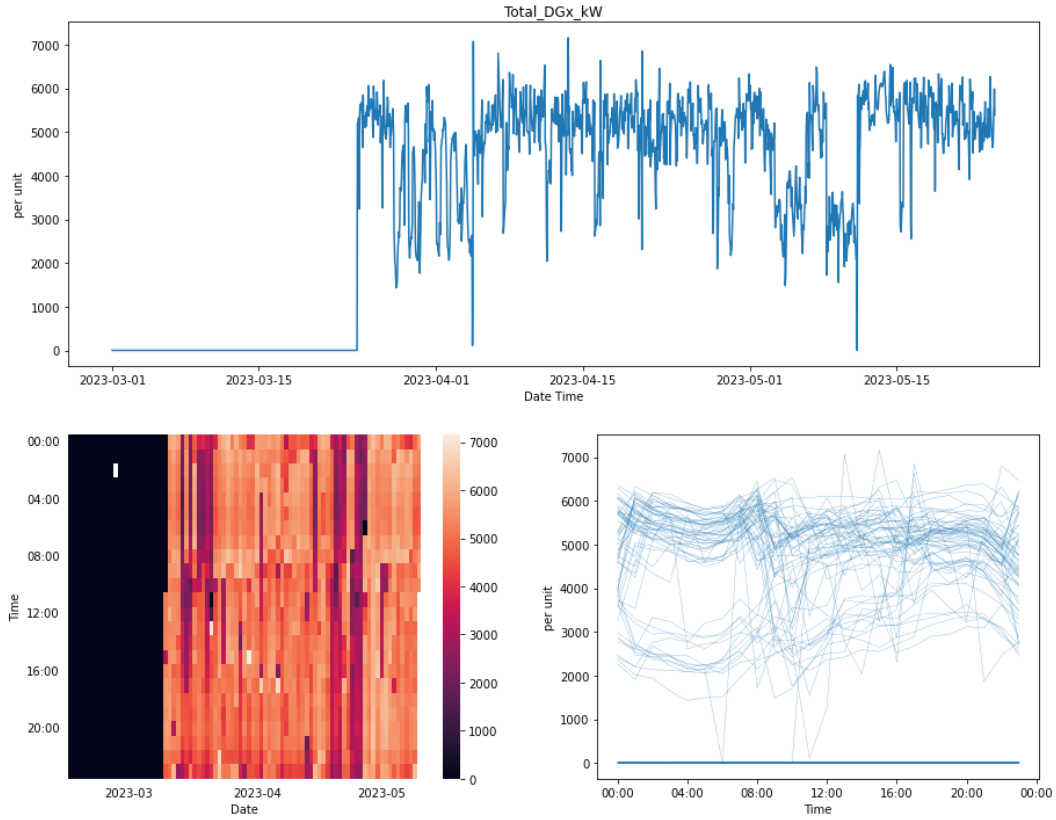

Figure 12: Three Plots of Aggregated DGx Generator Active Power

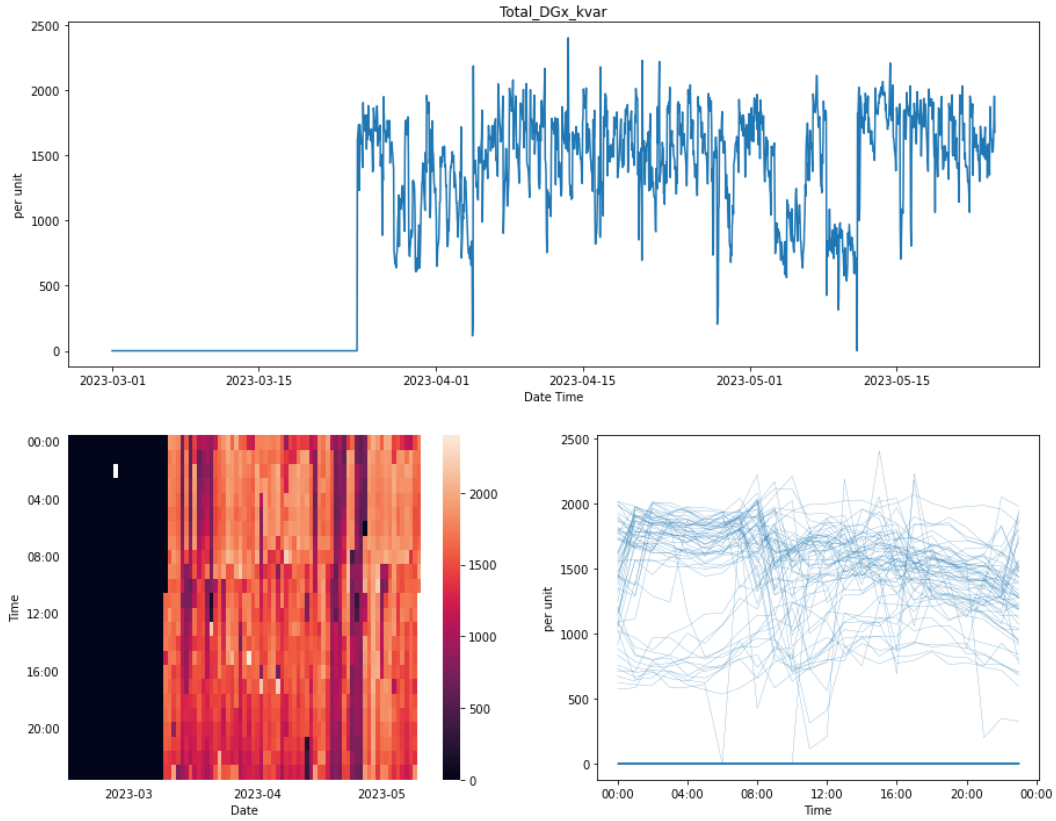

Figure 13: Three Plots of Aggregated DGx Generator Reactive Power

5 CONCLUSIONS

The purpose of collecting and analyzing the measured data was originally to support the modeling prior to conducting the transient stability analysis. This objective could not be achieved because the measurement data has become available too late in the project and because the data remains incomplete to this date: For Eleuthera, no measurement data is available from any feeders at Rock Sound Power Station and at Harbour Island Power Station. For Exuma, measurement data is available only for two generators (with more being likely in operation) and the load distribution across the feeders is not available.

The present report describes the basic analysis that has been carried out on the available data. The most relevant information has been extracted and visualized. The process gives an idea on how more analysis could be performed in subsequent work in other projects once more data becomes available.

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