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

RECOMMENDATIONS FOR GRID STABILITY AND RENEWABLE ENERGY INTEGRATION

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1 INTRODUCTION

This document describes the recommendations developed by Energynautics for power system stability and renewable energy integration into 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:

- Summarize the assessment criteria that should be considered in the evaluation of technological options to maintain and increase power system stability, safety, reliability, and efficiency while integrating increasing shares for (especially variable) Renewable Energy (VRE);
- Summarize the key characteristics of the power systems on the islands of New Providence, Eleuthera, and Exuma on The Bahamas, and highlight the key distinguishing features that influence the respective assessment;
- Discuss a range of technological options to maintain and increase power system stability in alignment with the transformation to sustainable power systems in the time frame until 2030;
- Provide recommendations for the most suitable options.

The recommendations are mostly based on the results of the transient stability studies carried out by Energynautics in this assignment. Due to the challenges observed with obtaining detailed data on the power system infrastructure and operation, in particular with regard to the systems on Eleuthera and Exuma, it is not possible to confidently make detailed and quantitative recommendations. Significant portions of the simulation models had to be based on various assumptions made by the consultants. Hence, the recommendations offered in this report remain rather more vague and general than originally intended in the inception of this project.

2 ASSESSMENT CRITERIA

The identification of the most suitable technological options for any given task depends on the context of the application. For any option to be considered suitable it must be readily available, provide a good benefit over cost ratio, and comply with requirements relating to environmental and social acceptability. Gender specific impacts of options should also be identified.

2.1 TECHNICAL AVAILABILITY

Generally all technical options require investment for implementation. However, solutions representing mature technologies up to the state of the art can be implemented faster than other solutions that still need further development and market readiness.

2.2 FEASIBILITY, COST AND BENEFIT

Depending on the scale of the power system, conducting feasibility studies and cost-benefit analyses before the implementation of any particular technology are suitable. The level of detail and complexity of such studies and analyses can be significant, therefore only basic investigations are typically performed for small island systems.

No feasibility studies or cost-benefit analyses have been carried out in the scope of the present project. Any statement regarding feasibility or cost over benefit ratio of any particular options are based on estimates by the consultants.

2.3 ENVIRONMENTAL AND SOCIAL ASPECTS INCLUDING GENDER IMPACT

Widespread neglection of environmental and social aspects in investment decisions has been contributing significantly to the challenges faced by societies today. It is therefore virtually necessary to include respective considerations in the evaluation of technological options for potential implementation. In this context it should also be investigated if there are impacts that do or may apply differently to men and women, so that the gender impact can be included in the decision making, and implementation measures can be accompanied by steps aiming to reduce disadvantages to specific societal groups. Guides and tools for performing gender mainstreaming are available from (CTCN 2017), (UNIDO 2021), (Green Climate Fund 2017).

A gender impact study has been carried out in this project accompanying the stability study for New Providence; however, gender impacts of measures related to increasing power system stability have not been identified.

No other analysis of environmental and social impacts has been conducted in this assignment. Statements made in the present report relating to environmental impact are based on estimates by the consultant.

3 POWER SYSTEMS OVERVIEW OF NEW PROVIDENCE, ELEUTHERA, AND EXUMA

The characteristics of the power systems on the investigated islands provide further context for the assessment of suitable technological options.

3.1 KEY FIGURES

Assumed approx. values	New Providence	Eleuthera	Exuma
Peak load base year	260 MW	24 MW	13 MW
Minimum load base year	107 MW	13 MW	8 MW
Maximum voltage level	132 kV	33 kV	33 kV
Renewable energy share (base year/intermediate/2030)	0% / 5% / 30% (2020/2023/2030)	10% / 20% / 30% (2023/2026/2030)	10% / 20% / 30% (2023/2026/2030)
Topological features	Meshed with radial segments	Radial / long and narrow	Radial / long and narrow

3.2 ACTIVE POWER LOSSES AND VOLTAGE ISSUES

In the inception phase of this project there has been an allusion to voltage issues as well as high active power losses on the island of Eleuthera. Identifying countermeasures to these issues would have been part of the stability investigations. However, it has not been possible in the modeling and simulation phase to adequately represent and analyze the issues. The power system data available upon which to build the simulation model has not been sufficient to confidently trust the model and simulation results to reflect the reality of the power systems on Eleuthera and Exuma. The issues therefore remain vague and no specific recommendations could be developed to resolve them.

3.3 (POTENTIAL) TRANSIENT STABILITY ISSUES

As mentioned before, the presence of transient stability issues cannot be demonstrated using the available simulation models due to lack of sufficiently detailed modelling data and corresponding model validation. However, the following stability issues can often be observed in island power systems, including with increasing shares of renewable energy:

- Frequency stability issues due to the combination of wider variability of residual load (demand minus uncontrolled generation) with reduced system inertia due to displacement of synchronous machine with inverter-based generation;
- Rotor angle stability and voltage stability issues due to limited ability of inverter-based generation to provide reactive current to support the grid voltage during voltage dips caused by short circuits.

4 TECHNICAL OPTIONS FOR GRID STABILITY WITH INCREASING SHARES OF VRE

The following subsections briefly discuss several technological options that could be used to address stability concerns in the power systems.

4.1 APPLICATION OF BATTERY ENERGY STORAGE SYSTEMS (BESS)

Battery energy storage systems (BESS) are well-suited for mitigating frequency stability issues due to their ability of balancing the variability of the demand and of the uncontrolled generation (together the variability of the residual load). Several battery technologies are available on the market. The dominant technology for new applications is lithium-ion. Although prices have declined significantly in recent years, battery storage is still expensive, hence care must be taken to pick design parameters suitable for the system and their application use case.

The most important design parameters are the power capacity and the energy storage capacity. The power capacity should be high enough, but not too high because otherwise it may cause issues if too high power is drawn from the grid. Also the selection of suitable installation locations plays a role here.

4.2 APPLICATION OF OTHER ENERGY STORAGE OPTIONS

The only two other common energy storage options for balancing electricity are pumped hydro and (in special applications) flywheels. Due to the topology of the Bahamas, pumped hydro is not an option. Application of flywheels has not been investigated in the present study since more confidence in the models would have been needed for such an investigation. Flywheels only address short-term variability in the time frame of seconds to minutes, but are typically not suitable for diurnal storage cycles such as for balancing the variability of solar power.

4.3 CONNECTION REQUIREMENTS FOR VRE GENERATION FACILITIES

Besides application of electricity storage, it is always a good idea to require grid-friendly behavior from renewable generation. The requirements should be imposed as connection requirements in Grid Codes. Regardless of the size of renewable generation, facilities should be required to be able to provide high voltage and low voltage ride through, to reduce their power output during overfrequency events, to have configurable reactive power output characteristics, and to temporarily operate at reduced power output on remote request of the system operator (without manual intervention). The grid code’s connection requirements should be reviewed and be updated regularly to follow the technological development and progress of the state of the art. (IRENA 2022)

4.4 APPLICATION OF GRID-FORMING INVERTERS IN BESS AND VRE GENERATORS

Grid-forming inverters are a particularly interesting option for BESS in island systems. With adequately sized inverters and storage attached, several examples on islands across the world (e.g., Hawaii, Faroe Islands) demonstrate that very good frequency stability can be achieved, and also good voltage quality. (IEEE Electrification Magazine 2022)

Grid-forming inverters for VRE generators are not yet state of the art, and this is unlikely to change in the near future. This is because grid-forming functionality implicitly requires at least a small amount of energy storage (making VRE generators more expensive) and there is not yet any established standard on what precisely 'grid-forming' means in terms of inverter control functionality and how to specify the same in Grid Codes.

4.5 DEMAND-SIDE FLEXIBILITY

Unlocking the highest levels of variable renewable energy integration, even with energy storage available in the system, will require activation of demand side flexibility as well in order to be efficient. As of today, demand side flexibility from certain suitable industrial facilities is already used in some power systems, but more research is carried out to investigate how much flexibility smaller consumers can contribute and how it can be integrated in the most efficient manner.

4.6 UPGRADING AND EXPANDING THE GRID

Besides application of new technologies, some stability issues can also be efficiently addressed using conventional measures. This includes strengthening the grid infrastructure by upgrading and expanding substations, line, cables, and transformers; upgrading monitoring and control systems, and deploying synchronous condensers, STATCOMS or SVCs to provide reactive power support.

5 RECOMMENDATIONS

The recommendations are mostly based on the results of the transient stability studies carried out by Energynautics in this assignment for New Providence (Energynautics GmbH 2022) as well as Eleuthera and Exuma (Energynautics GmbH 2023). Due to the challenges observed with obtaining detailed data on the power system infrastructure and operation, in particular with regard to the systems on Eleuthera and Exuma, it is not possible to confidently make detailed and quantitative recommendations. Significant portions of the simulation models had to be based on various assumptions made by the consultants. Hence, the recommendations offered in this report remain rather more vague and general than originally intended in the inception of this project.

5.1 NEW PROVIDENCE

- If a centralized PV integration strategy is favored over a more distributed strategy with several utility-scale and commercial PV plants and significant residential PV, then multiple connection points should be used in order to avoid the introduction of single points of failure into the system.
- Introduction of battery electricity storage systems (BESS) is able to significantly contribute to balancing the variability of power generation from PV, supporting the frequency. A BESS facility with a capacity of 25 MW was used in the simulations and worked reasonably well. No size optimization exercise has been carried out by the consultants, and no assumption was made on the storage capacity (MWh) because it was not needed for the short-term analyses in the stability study.

5.2 ELEUTHERA AND EXUMA

- With rising shares of PV on Eleuthera and Exuma, installation of at least one BESS plant on each island is likely to become advisable, too. BESS of different size were used in the study (Exuma: 2 MW in 2023 and 2026, 4 MW in 2030; Eleuthera: 3 MW in 2023 and 2026, 5 MW in 2030), but again no size optimization was carried out by the consultants. When planning actual BESS facilities on the islands it is recommended to consider investing into grid-forming capability for the BESS plants.
- The location of new PV installation capacity should be allocated such that too high concentration of capacity is avoided and the loading on the 34 kV transmission line does not increase too much.
- The maintenance, supervision and monitoring of the power systems should be improved in order to increase data availability and enable validation of simulation models.

5.3 GENERAL RECOMMENDATIONS

- The technical connection requirements for new RE generation facilities should follow the state of the art of ‘grid-friendly’ capabilities available on the market. All new RE generation facilities should be able to ride through disturbances, adjust their power output to counterbalance frequency excursions (at least reduce their power output during overfrequency events), and should be able to respond automatically to temporary generation limits communicated by the system operator. Non-residential PV units should also be able to provide voltage support during undervoltage and overvoltage events. (IRENA 2022) (Peças Lopes und Moreira 2022)

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