Increasing Renewable Contributions in Island Utility Grids

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***Abstract*— Globally, island electricity systems are on a journey to reduce energy costs and break their singular reliance on imported diesel and heavy fuel oil for their electricity. As the costs for renewable generation and battery energy storage decline, island utilities can create increasingly resilient, lower-cost energy supplies while meeting domestic goals on the use of renewable energy. Intelligent controls and smart automation are critical technologies for enabling island utilities to unlock the benefits of the low-cost solar photovoltaics (PV) and battery energy storage systems (BESS) available today.**

This paper is divided into three sections. In the first section, business case for a theoretical island utility, we establish the economic case for an island utility to use smart automation and controls to unlock the benefits of PV and BESS. In the second section, technical simulation of BESS performance, we assess and summarize the technical benefits for a specific 10 MW BESS project in Grand Bahama with a focus on grid stability and high-power quality. The third section, measured operational results, includes operational data for this project showing frequency and voltage support provided by BESS.

Keywords-component; Island Utility, Power Quality, Battery Energy Storage Systems, Solar Photovoltaics, Spinning Reserve.

I. INTRODUCTION

Island utilities are, traditionally, reliant on costly imported diesel and heavy fuel oil for their electricity. This singular reliance on an expensive resource has led island utilities to pay some of the highest and most volatile electricity costs in the world. It is not uncommon for island utility customers to pay between 0.20 and 0.50 USD/kWh for their electricity — two to five times what many customers of mainland utilities might pay. Beyond the high cost, these fuels are toxic and contribute to climate changes that are eroding shorelines and affecting the environmental stability of many islands.

To meet these goals, islands will rely on renewable energy with support from BESS with smart control and automation solutions. This island energy transition is technically viable and can economically reduce the risk and exposure to fossil fuels. As compared to mainland utility grids, island grids have less diverse generation and demand, do not interconnect with larger networks and tend to lack secure and reliable network infrastructure. One key economic driver is reduced technology costs: installed solar PV prices have declined around 80 percent over the past eight years, while lithium-ion battery pack prices have dropped around 80-90 percent in the same timeframe. Cost declines for these technologies are projected to continue.

As renewable and storage prices fall, fossil fuel prices continue to spike and disrupt island economies. Renewable and storage investments can protect utility rate payers from fuel volatility, while supporting the islands in achieving their environmental and domestic energy goals. There is no technical limit to higher contribution of renewable energy; it is expected that the contribution of renewable energy possible at least cost will continue to improve as technological innovation continues.

This paper will discuss the business case for inverting in energy storage and PV for a theoretical island utility. Then, it will demonstrate dynamic simulations for the specific Hitachi ABB PowerStore BESS in Grand Bahama. Grand Bahama Power Company (GBPC), part of Emera Caribbean Inc. (ECI), is the fully integrated electrical utility responsible for serving the 65MW peak load island of Grand Bahama pre hurricane Dorian and COVID-19. Their generation portfolio consists primarily of diesel and light oil-fueled reciprocating engine-driven generators with growing amounts of renewable generation. In addition to the renewable transition, the island is facing multiple challenges due to the dynamic and volatile load of industrial cranes and excavators for mining operations. The dynamic load has sub-second load swings larger than 8 MW which results in the utility carrying an unusually high spinning reserve to increase the system inertia to limit frequency swings on the electric grid. When these industrial customers are operating, the increased spinning reserve results in accelerated wear and tear on engine components and high plant heat rates [1].

Even with this increase in spinning reserve, the system still experiences frequency excursions in the +/- 1.0 Hz range due to the relatively low system inertia and inherent slow response of the diesel driven generation to such transient events. GBPC has partnered with Hitachi ABB Power Grids to install a 9.6 MW and 7.6 MWh PowerStore BESS with primary values to smooth the load profile of industrial customers, provide grid frequency regulation, and provide spinning reserve to operate generator engines at higher efficiencies and reduced engine operating hours. The BESS also provides voltage support and supports integration of future renewable energy generation.

This paper investigates the impact of the BESS with smart automation and controls on GBPC network dynamics and stability prior to the dual cataclysmic events of Hurricane Dorian and the COVID-19 pandemic. Load step changes were simulated to demonstrate the network response before and after BESS integration, resembling the dynamic industrial loads. The voltage and frequency ride-thorough capabilities of the BESS are demonstrated in case of generator trip and fault events. Then, the stability of the BESS controls verified by against a weak system condition. Finally, the operational data from BESS operation after COVID 19 and the hurricane is presented.

II. Business Case for Island Utilities

This business case considers a base case and three renewable and BESS investment scenarios optimized using the HOMER Pro microgrid modeling software. For each scenario, we assume an island with an 11.2 MW average load, and peaks up to 15 MW. The island has a 2.0 MW spinning reserve on top of the load, based on supporting a contingency event that causes an entire generator to drop offline.

The island electrical grid is managed by a local utility. The existing generators are fed with diesel fuel that has a fully-delivered price of 0.75 USD/L, inclusive of transport, taxes and other costs. This business case focuses on new (i.e., marginal) investment costs for the island utility, because those are the economics that affect the decision. The total CAPEX of the installed solar PV system, including PV inverter, is 1.50 USD/W_p. The PV arrays receive an average 5.5 kWh/m^2/day of solar irradiation. To account for intermittent cloud cover, 75 percent of the PV's power output must be covered by spinning reserves from the diesel generators or the BESS. The BESS uses lithium-ion batteries and the round-trip efficiency is assumed to be 90 percent. The BESS and converter system has a capital cost of 300 USD/ kWh combined with 500 USD/kW and a fixed 100 kUSD for delivery, controls and balance of plant.

All cost assumptions are chosen to reflect higher construction costs in typical island locations but may be higher or lower for other locations. A 9 percent discount rate with 2 percent inflation rate was applied to future cash flows.

Under the base case, the island utility continues to operate exclusively on diesel generation. The utility regularly uses nine 2 MW diesel generators that each have a continuous minimum load rating of 600 kW. During times of peak power usage, eight gensets are necessary to serve the load directly, while the ninth is online to handle occasional load spikes. Without this ninth unit to supply spinning reserve, the utility would need to shed load during load spikes or risk blackouts. During off-peak times, fewer diesel generators are required to operate, but there typically remains an extra unit online to handle load spikes. In terms of operations, in a traditional island utility there is limited generation automation and the operators at the utility plant must manually control their diesel generators.

A portfolio based entirely on diesel leaves the utility and its ratepayer extremely exposed to the volatility of the petroleum markets. The utility consumes 446 barrels of oil a day to provide power to the island residents, and the levelized cost of energy (LCOE) for the generation cost passed through to utility customers is 0.223 USD/kWh, in addition to the utility's administrative and distribution costs.

A summary of the base case and investment scenario results are presented in Table 1. From this table, we can see that:

1. The high renewable scenario yields both the greatest savings and the greatest contribution of renewable energy. Although this scenario yields the greatest economic savings, even higher renewable contributions are possible with Hitachi ABB Power Grids e-mesh.

2. The renewable ready BESS investment provides value at a strong return.

3. The medium renewable scenario bridges the gap for islands that still want to use renewable energy but limit the capital outlay.

4. All three investment scenarios represent a step toward island goals of using more renewables, decreasing costs and reducing the reliance on volatile energy sources.

TABLE I Summary of investment scenario results

Scenarios	PV (MW)	BESS (MWh)	Capital cost (MUSD)	Operating cost (MUSD)	LCOE (USD /MWh)	IRR (%)	Payback (years)	Renewable contribution (%)
Base case: diesel only	0	0	0	23.0	233	--	--	0
Renewable ready	0	3	3	22.2	227	27	3.8	0
Medium renewable	10	5	20	18.2	203	24	4.1	20
High renewable	20	10	43	14.8	190	19	5.3	35

III. Dynamic Simulation of BESS Integration

The GBPC power system is supplied by two-diesel-powered generation systems. The Peel St. Power station (PSP) and West Sunrise Power station (WSP). PSP has two 13.5 MW units and one 18.5 MW unit. WSP has six 8.7 MW units. The under-frequency load shedding scheme (UFLS) contains both threshold and rate-of-change of frequency implemented as load relays in PSS/e model. The total system load ranges from 65 MW to under 30 MW. The 9.6 MW and 7.6 MWh BESS is connected to the network.

The evaluated BESS is designed for both grid-connected and off-grid applications, ensuring reliable power, seamless renewable integration and grid stability while reducing operating costs and complying with main grid codes and standards [2]. Key automation features of the described BESS system include: peak shaving, renewable shifting, frequency and voltage support, renewable smoothing (smoothing out rapid fluctuations in power output from renewable generators and/or dynamic loads), microgrid capability with seamless islanding, and cyber-security The BESS ensures a high-level of cyber security according to both NERC-CIP and IEEE 1686. [3]

Three main events are tested on the GBPC network in PSS/e to evaluate the impact of the BESS on the utility grid. These events are load step changes, generator trips and network faults, and a weak grid system evaluation considering a hurricane-like event. The analysis for each event is presented in the following.

A. Stability through load step-change event

The island has industrial loads with frequent, sub-second load swings larger than 8 MW. The stability of the island utility in the 8 MW step-change load before and after BESS integration is demonstrated in Fig. 1 to Fig. 2. As shown in Fig. 1, the frequency drops to 58.68 Hz (-0.022 p.u. deviation) after the disturbance and then recovers following an UFLS operation at 2.26 second. As shown in Fig.4., the BESS reached 90% of the load step-change in 0.07 second after the disturbance while the frequency is reduced to 59.88 Hz. Hence the BESS not only avoided the load shedding but also reduced the wear and tear on online generators.

As shown, the BESS reaches 90% of the change in less than 0.1 second. The BESS response time is calculated from the disturbance time to the time ESS reaches 90% of the change.

B. Ride through during generator trips and network faults

The BESS has Frequency Ride-through (FRT) and Voltage Ride-through (VRT) capabilities. Hence, it will ride-through disturbances, rather than compounding the severity of the event with subsequent tripping of the energy storage system. The BESS can continue operation within +/- 5 Hz of nominal 60 Hz.

The BESS will ride through the generator trip events as illustrated in Table II. As shown for the light load case, the generator trip has caused the frequency nadir of 57.66 Hz with 11 MW of load shedding. While, the BESS has reduced the frequency drop to 58.62 Hz, avoiding the load shedding. The load shed in not avoided in winter peak case, since the frequency nadir is less than the first threshold point in the UFLS relays. On the other hand, load shedding and frequency nadir are reduced after integrating the BESS.

The BESS will also ride-through the fault events with breaker failures as shown in Table III. The events are simulated by applying single-phase (1ph) and three phase (3ph) faults at 69 kV bus at the time of 1 second and clearing fault at time of 1.3 second. The BESS low voltage block is tuned at 0.25 p.u. and the high voltage block is tuned at 1.3 p.u. The unblocking time is 0.15 second. As shown in Table II, since the minimum voltage in the 3-phase fault case is lower than 0.25, the BESS is blocked. Then, the BESS responds at 1.45s, which is 0.15s (unblocking time) after fault clearance time (1.3s). Since, the minimum voltage for the 1-phase fault event is above the low voltage block, the BESS responds at 1.03 s (which is only 0.03 second after the fault and before fault clearance). The BESS help the system restore voltage and frequency in both events.

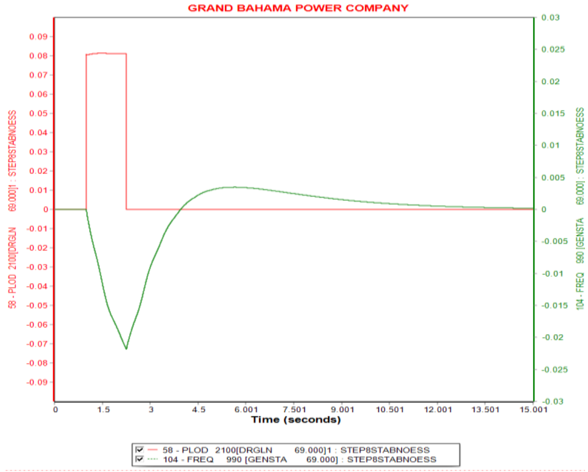

Fig. 1 Frequency (green line) and load (red line) profiles through 8 MW load step-change before BESS integration

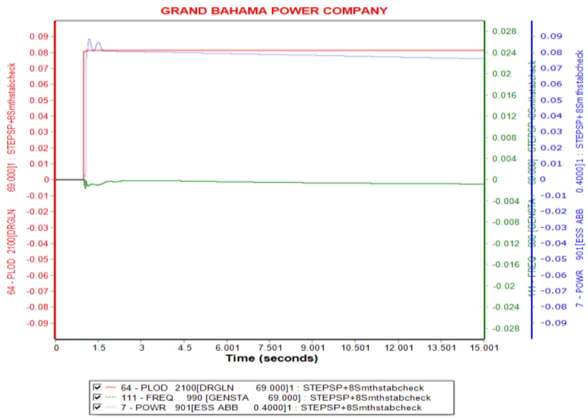

Fig. 2 Frequency (green line) and load (red line) profiles through 8 MW load step-change after BESS integration

TABLE II RIDE THROUGH CAPABILITY FOR GENERATOR TRIP EVENTS

Case	Frequency Nadir (Hz)		Load Shed (MW)		Generation change (MW)		ESS Output (MW)	
	w/o	w/	w/o	w/	w/o	w/	w/o	w/
Light Load	57.66	58.62	11	--	11.1	11.2	-	11.2
Winter Peak	56.64	57.96	21.2	8.5	21.4	16.8	-	8.3

TABLE III RIDE THROUGH CAPABILITY FOR FAULT EVENTS

Event	Frequency Peak	Frequency Nadir	Max Voltage	Min Voltage	BESS Start Time
3ph fault	62.28 Hz at 1.33s	59.82 Hz at 1.83s	1.207 pu at 1.37s	0.003 pu	1.45 s
1ph fault	60.54 Hz at 1.27s	59.82 Hz at 2.41s	1.283 pu at 1.40s	0.623 pu	1.03 s

C. Weak Grid System Evaluation [as in a hurricane]

The objective of this section is to adapt the utility network to simulate a weak grid system in case of hurricane hitting the island and the need to black start the grid. Hence, the system is remained with only one West Sunrise unit, 6.6 MW of load, and the 9.6 MW and 7.6 MWh BESS. The event of switching in an additional 6 MW + 2 MVA load is performed to evaluate the system stability. The impact is shown in Fig. 3 and Fig. 4. The frequency collapses and results in power system instability. The frequency deviation reaches –2.3 p,u, at the end of the 20 s simulation. The generator oscillates after the event. The impact of "Event b" with the BESS is shown in Fig. 5 and Fig. 6. The BESS provides response 0.02 second after the event and reaches 90% of load change in 0.08 second. The frequency is stable with max deviation of -0.004 p.u. The BESS stabilizes the system by prompt response to frequency deviation and prevents generator's oscillation and frequency collapse. Results are shown in Table III.

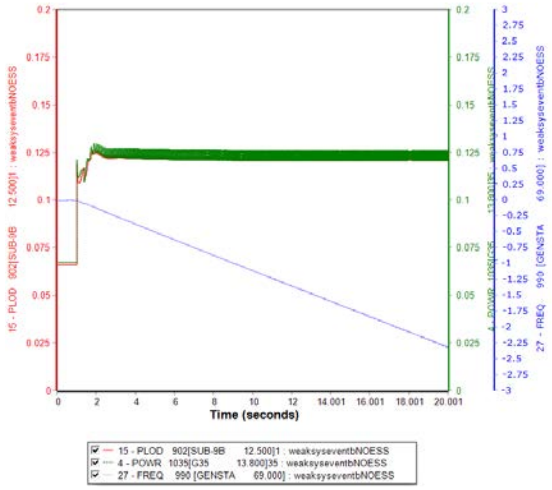

Fig. 3. No BESS Scenario, load change in red, Active power load in red, Active Power from Gen in green, Frequency in blue

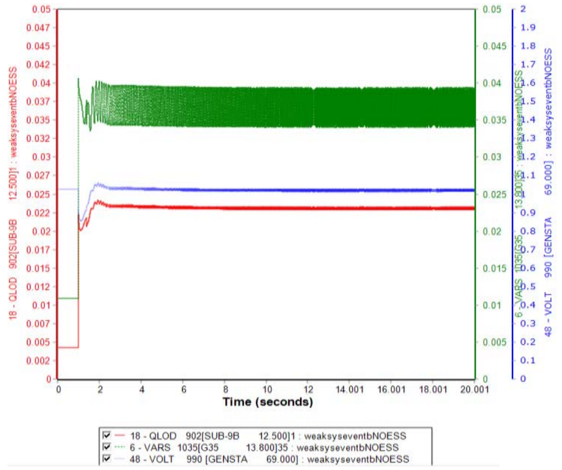

Fig. 4. Reactive power load in red, Reactive Power from Gen in green, Voltage in blue (right)

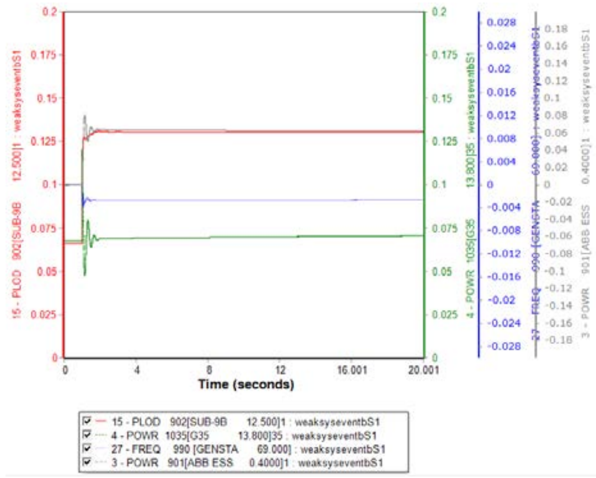

Fig. 5. BESS Scenario, Active power load in red, Active Power from Gen in green, Frequency in blue, Active Power from BESS in grey

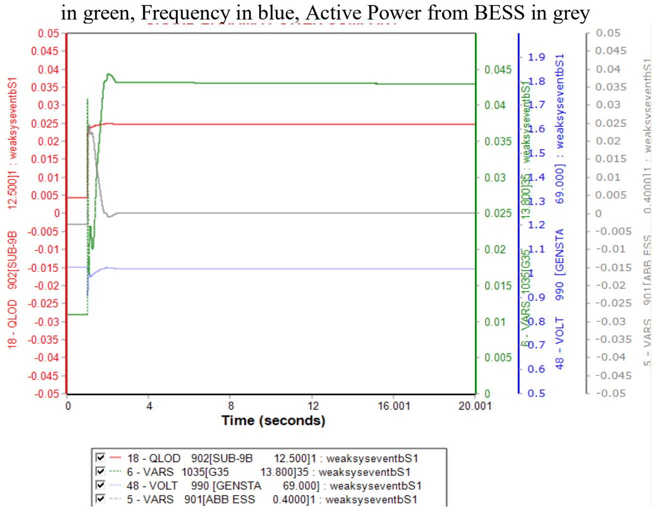

Fig. 6. BESS Scenario, Reactive power load in red, Reactive Power from Gen in green, Voltage in blue, Reactive Power from BESS in pink (right)

TABLE III
SIMULATION RESULTS FOR WEAK GRID SYSTEM

	Measured Parameter	Weak System	
		No ESS	ESS
Event	Max Frequency Deviation (p.u.)	-2.3	-0.004
	Time BESS starts (s)	--	0.02
	Time BESS reaches 90% of load change (s)	--	0.08

IV. MEASURED OPERATIONAL RESULTS FOR THE BESS

The BESS project went operational in early 2019 and helped the utility during power restoration after Hurricane Dorian hit the island. The BESS solution is providing frequency regulation and power quality improvement for industrial loads on the island. The operational data for the BESS is extracted with 10 second time resolution from GBPC's SCADA for the full day on Tuesday September 1, 2020.

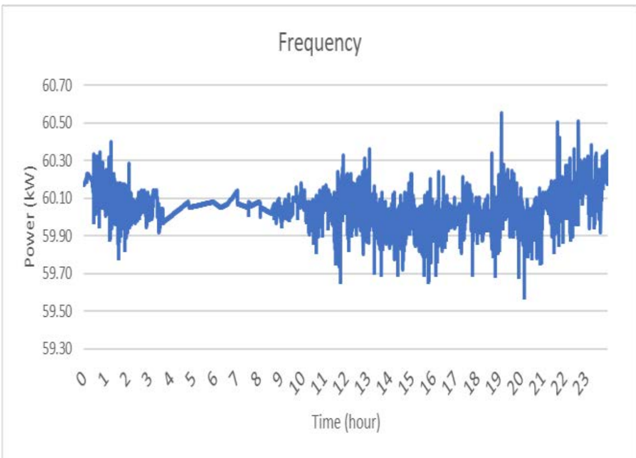

Fig. 7. Frequency [with BESS] for Grand Bahama Island on September 1, 2020

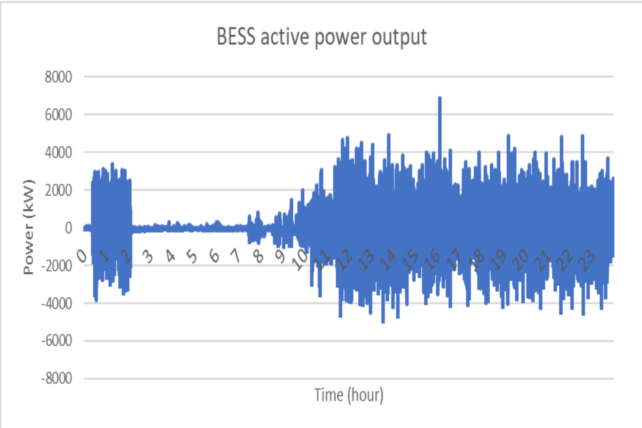

Fig. 8. BESS active power output on September 1, 2020

The system frequency and BESS active power are shown in Figures 10 and 11, respectively. As shown, the BESS kept the frequency within the desired range and provided power when there was a need to regulate frequency. The frequency deviation matches the working hours for the industrial site operation at the port, and the BESS has smoothed the loads.

V. CONCLUSION

Island utilities have more options for serving their customers with better power quality than ever before. Previously, they were limited largely to diesel and heavy fuel oil-based generation. However, today there are options to diversify their supply with renewable energy and battery energy storage. In addition to being less expensive and reducing energy price volatility, these options help to meet renewable energy goals.

Investments in renewable generation, BESS and smart control technologies can make islands less vulnerable to market conditions, more resilient to environmental challenges and increase energy security by using domestic energy sources.

The results of the stability studies performed with the BESS reflect promising results to improve the power quality in GBPC network by smoothing the large, volatile dragline and crane loads as well as providing network voltage and frequency support. The BESS can respond within 70ms to provide load smoothing control and improve power quality in the simulation.

By integrating the BESS, generators trips are reduced, which reduced wear and tear on generators yielding less maintenance and fewer capital replacements for engine components. The BESS also improves customer reliability. In several events of generators tripping, the BESS provide power to the grid, providing synthetic inertia to arrest the frequency drop which historically would result in a load shedding event.

The BESS provides reactive power during fault events to restore voltage, which limits brown- and blackout conditions in the grid. The BESS also features frequency and voltage ride-through capabilities and is able to operate continuously through disturbances. In the case of a weak grid system, the BESS avoided frequency collapse and was beneficial to system stability. This has dramatic benefits, particularly in weak grid networks prone to major disruptive events such as hurricanes.

The simulated benefits were validated from actual operational data from the day of September 1, 2020. The BESS provided needed frequency support and power quality improvement, particularly when dynamic industrial loads were operating on the island.

Proven advanced integration technologies and controls create an opportunity for island [and other] utilities to leapfrog the challenges of utilities in larger markets. Global experience with projects like the BESS and automation solution at Grand Bahama Power Company demonstrate that the technology has benefits in terms of economics, reliability, and using BESS to create a cost-effective electric network backbone for future renewable integration.

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