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Island Interconnected Microgrids for Resilience

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SUMMARY

High impact low frequency events such as wildfires and hurricanes create very challenging operational and investment strategies for utilities. The long duration outages caused by these natural disasters propagate well into community lifelines and have important consequences to society. Meanwhile, the mission of electric utilities is to maintain power system reliability, which is intended to upkeep the system from low impact high frequency events, also referred to as blue sky operation. Bridging the gap between resilience and reliability is challenging, although necessary as high impact events become more common, at the same time the general public becomes less tolerant to power system interruptions. This need led utilities and customers alike to explore the application of microgrids coupled with advanced controls. This paper analyses the impact of past weather events on the electricity supply of an interconnected island electric utility system. It develops a techno-economic analysis and proposes an optimum microgrid solution as well as voltage management study. The investigation suggests a favourable benefit-cost analysis and a compelling case for a microgrid.

KEYWORDS
Distribution system reliability, microgrids, outage restoration, reliability, resilience.

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1. INTRODUCTION

Electric utilities around the globe are striving to adapt to more frequent major weather events, such as wild fires, hurricanes and floods. As an essential service to society [1], maintaining electricity service during these high impact, low frequency events is challenging. More challenging is the fact they are gradually becoming more frequent and damaged infrastructure not always can be restored to its original state. Planning for blue sky operation may no longer be sufficient [2]-[3] and adapting standards, guidelines and best practices to dark sky events is becoming the new norm for many T&D system operators [4].

As electric infrastructure is extremely costly, reinforcing the entire system without a strategic and targeted approach does not hold a business case [5]. In this realm, exploring all possibilities, including non-wires alternative solutions (e.g., energy storage and microgrids) is necessary and must be included in cost-benefit analyses. Among alternative solutions, the infrastructure, technological advances, and control systems that are the underlying foundation of microgrids have been shown to be an option that can provide the necessary resilience a community needs and can be economical in many cases [6], [7].

In this manuscript, the authors present a multi-island power system operated by a Caribbean utility that serves about 1.5M metered premises and provides electricity to about 3.2M people. Two minor islands of this system, dwelling under 10,000 residents, are the focus of this work. A microgrid sizing exercise is developed, consisting of aggregations of DER and leading up to an interconnected microgrid architecture to leverage renewable generation and energy storage systems. Renewables will possibly be integrated through utility-scale, utility-owned resources or third party-owned resources through renewable procurement processes. The paper also presents a voltage and power flow study illustrating the needs for system upgrades to support large amounts of renewable generation.

2. THE MULTI-ISLAND TRANSMISSION AND DISTRIBUTION SYSTEM

This paper is focused in a case study of a Caribbean multi-island transmission and distribution system. The main island is supplied by a 230kV backbone ring network supporting a meshed 115kV networked transmission system. It also contains a highly dispersed 38kV subtransmission system, which supplies direct some large loads but predominantly is stepped down to distribution level. The distribution system consists of about 1,400 distribution feeders predominantly supplied at five different voltage levels: 13.2kV, 8.32kV, 7.2kV, 4.8kV, and 4.16kV.

This paper focus on two small islands supplied at 4.16kV. These two islands are interconnected to the main island through a submarine cable operated at 38kV. Each cable segment is about 10 miles. These small islands each have a 38/4.16kV distribution substation each, and have three and two feeders, respectively, as illustrated in Fig. 1.

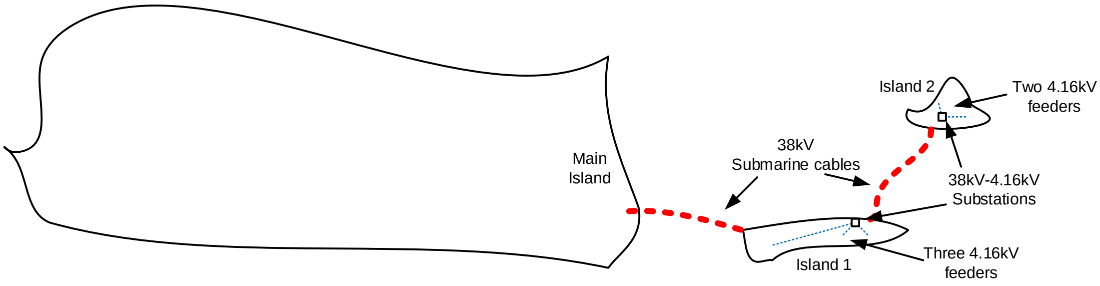


Fig. 1. A simplified representation of the island system (not to scale)

3. MICROGRID SIZING OPTIMIZATION AND SENSITIVY ANALYSIS

Different objectives were considered when deciding on the sizes of the PV generation and energy storage to be installed in both small islands. The microgrid optimization tool HOMER was used to size the DERs.

The following two objectives were considered:

Objective 1: Reduction in diesel consumption.

Objective 2: Reduction in excess energy.

The following four scenarios were considered:

Scenario 1: Island 1 is studied in isolation.

Scenario 2: Island 2 is studied in isolation.

Scenario 3: Islands 1 and 2 are networked and isolated from the main grid.

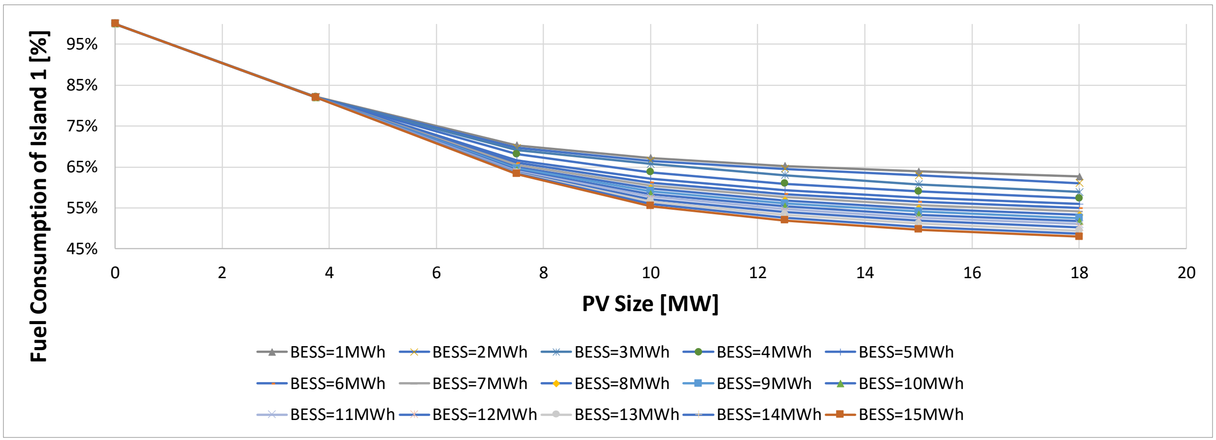
Scenario 4: Blue sky operation, i.e., both islands are connected to the main grid.

To reach a recommendation, an exhaustive search containing various microgrid scenarios was conducted. The loading for both islands for one year, using a one-hour resolution, was used. The sizing results are shown in Table 2. These results demonstrate that renewable energy curtailment is unavoidable under practical DER sizes, but scenarios can be optimized to reduce both objectives.

Table 2. Suggested sizes and their impact on diesel consumption and energy production

Scenario	BESS	PV	Objective 1	Objective 2	Energy offset
Scenario 1	7 MWh	12 MW	41%	13%	41%
Scenario 2	3 MWh	3 MW	35%	5%	35%
Scenario 3	10 MWh	15 MW	42%	14%	42%
Scenario 4	10 MWh	15 MW	N/A	0%	56%

The results from the exhaustive search conducted to reach these results is presented as a sensitivity exercise in Fig. 3, as it displays the impact of changing the configuration on the diesel consumption. This simulation considers any excess energy that may result from each case. It shows how both BESS and PV systems must be increased in size simultaneously to provide significant benefit and avoid a situation of diminishing returns.



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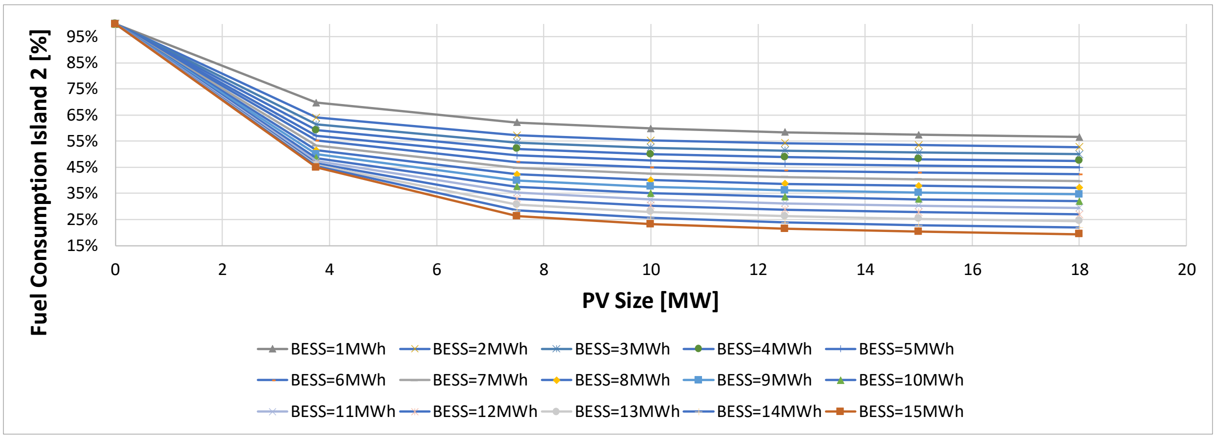

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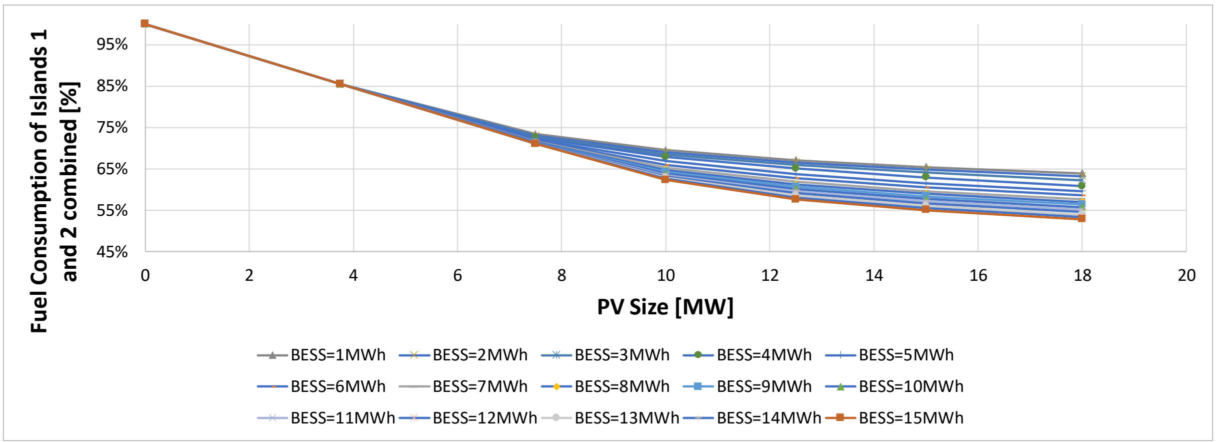

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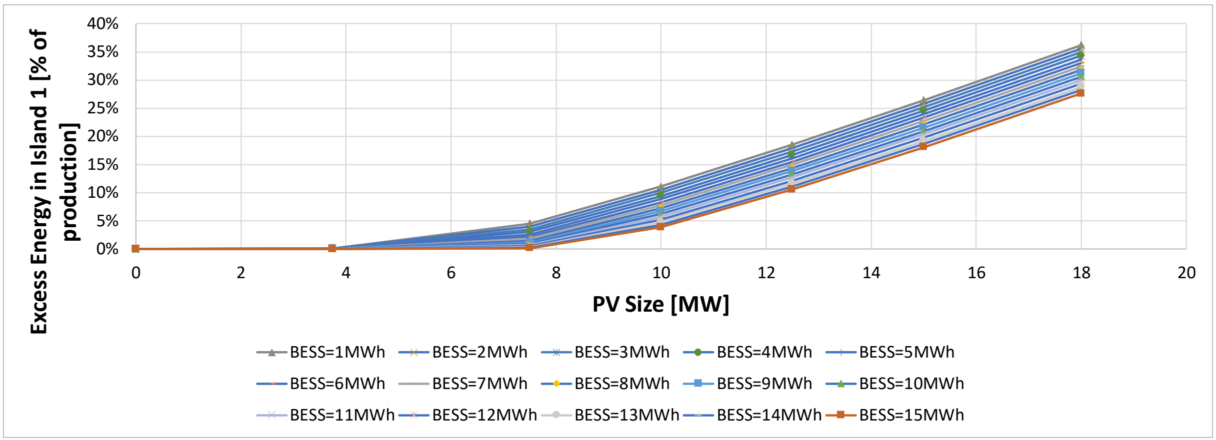
Fig. 3. Sensitivity analysis results for diesel consumption reduction of different scenarios, (a) Island 1 microgrid, (b) Island 2 microgrid, and (c) combined Islands 1 + Island 2 networked microgrids.

These simulations above were conducted assuming total loss of subtransmission 38kV supply (black sky event); this configuration results in major PV generation curtailment, as suggested by Fig. 4. However, the curtailed PV energy could be used under blue sky operation to further offset the total energy consumption of both islands when the subtransmission supply is available. For *blue sky* days, this microgrid will result in a substantial positive flow of renewable energy into the main island.



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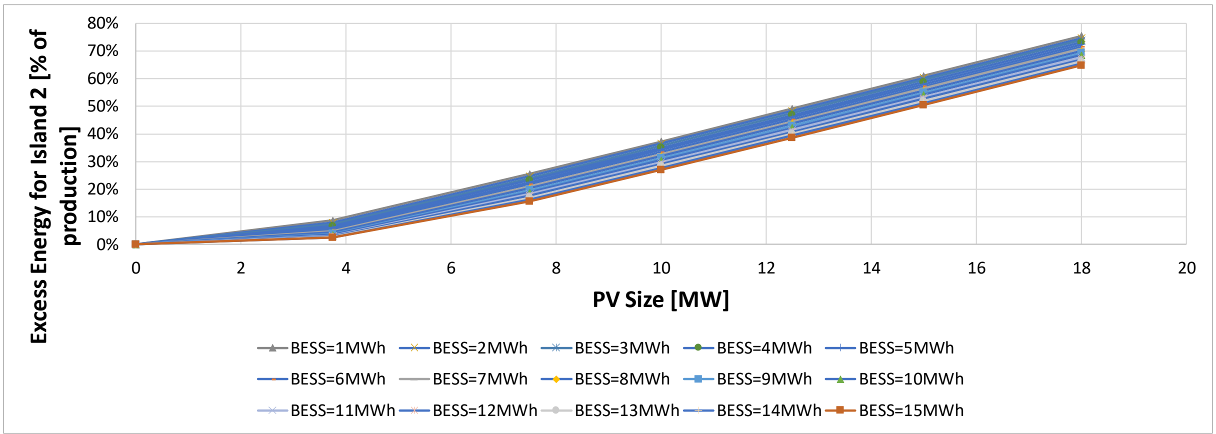

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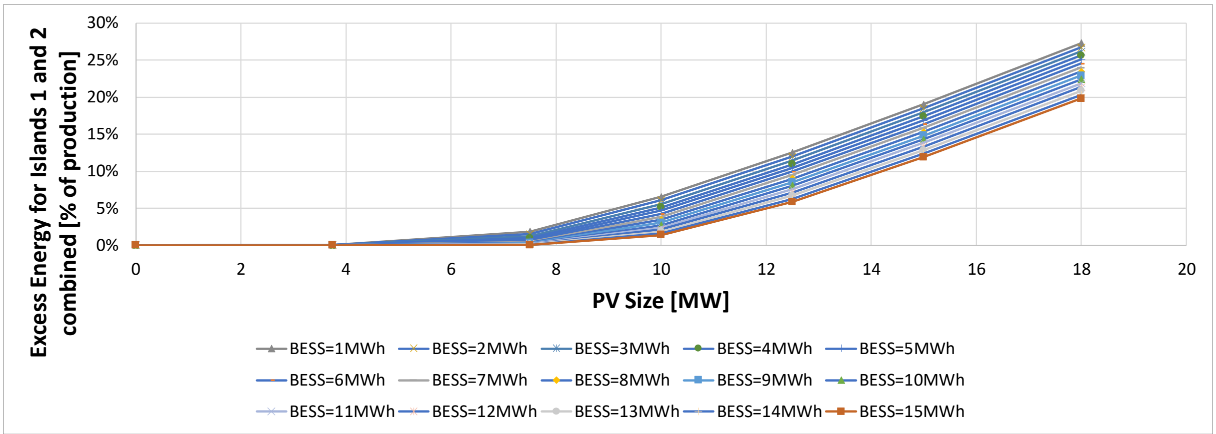

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Fig. 4. Initial feasibility analysis results showing excess energy of different islanded scenarios, (a) Island 1 microgrid, (b) Island 2 microgrid, and (c) combined Islands 1-2 networked microgrids.

4. VOLTAGE AND LOADING TIME-SERIES LOAD FLOW STUDIES

This study focuses on the existing and proposed system configuration and highlights the importance of voltage control. The submarine cable that connects the islands (refer to Fig. 1) are about 20 miles combined, which at 38kV contain significant charging current (due to cable capacitance). Fig. 5 contains different strategies for mandating inverter control (unity power factor, Volt-VAR, and Volt-VAR plus Volt-Watt) and how these strategies impact the proposed set-up by illustrating the amount of energy that will be exported (consequentially the rest will be curtailed) on a yearly basis. Default IEEE 1547 curves were adopted in the study. The amount of energy imported was not factored in to illustrate the impact of voltage control on energy exported. The figure also shows the amount of time the voltage exceeds the limits of 1.05 p.u. at 38kV in each substation. This scenario is clearly unacceptable and illustrates inverter control alone is not capable of maintaining safe voltage.

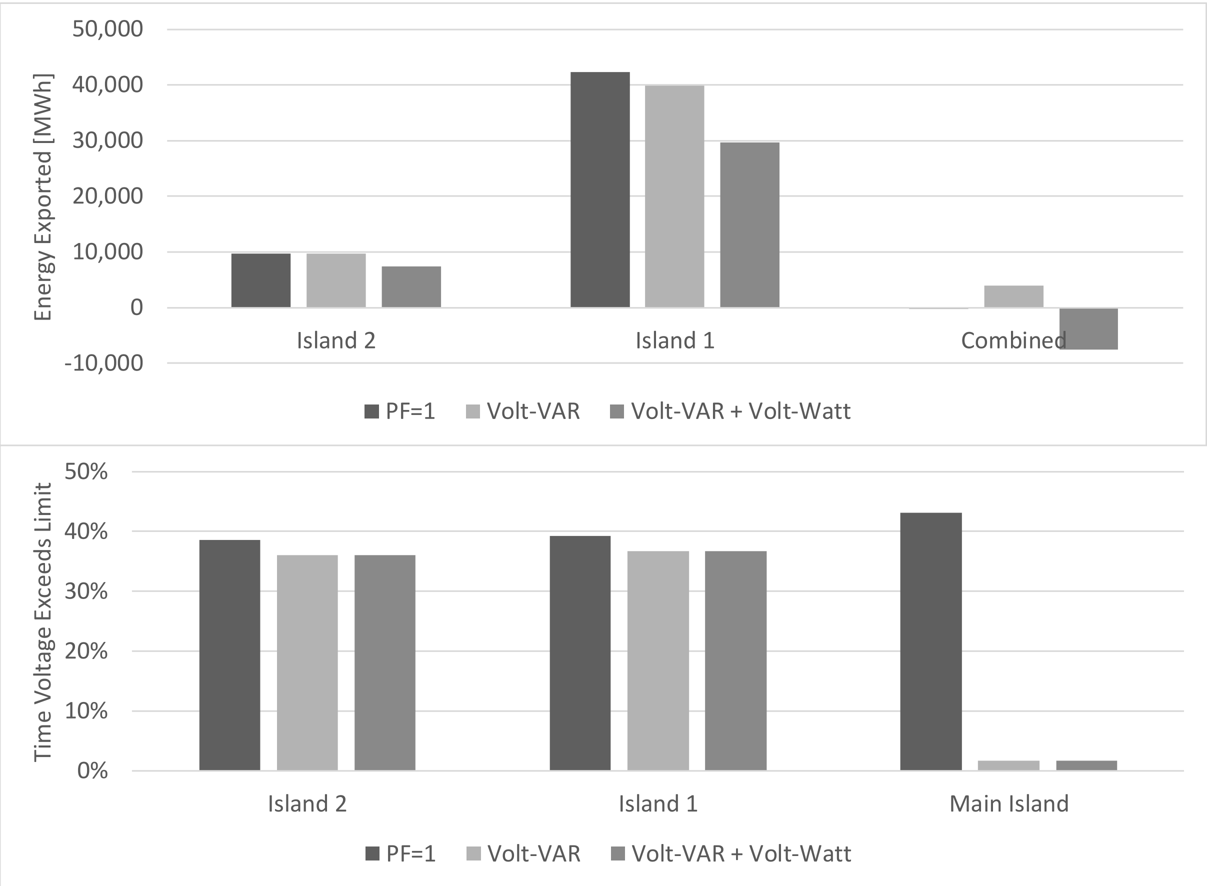

Fig. 5. Energy exported from each island as well as amount of time voltage limits are violated at each location under existing transmission system configuration

Conversely, Fig. 6 shows the same results when a 38kV voltage regulator is installed on the main island and regulates voltages at the point of interconnection departing to Island 1. The voltage regulator is very effective at limiting voltage, but PV inverter voltage control is still required (Volt-VAR recommended with Volt-Watt implemented as a safety feature). This illustrates the need to combining both solutions (i.e., inverter controls plus voltage regulation devices) to maintain safe voltages at the main point of connections.

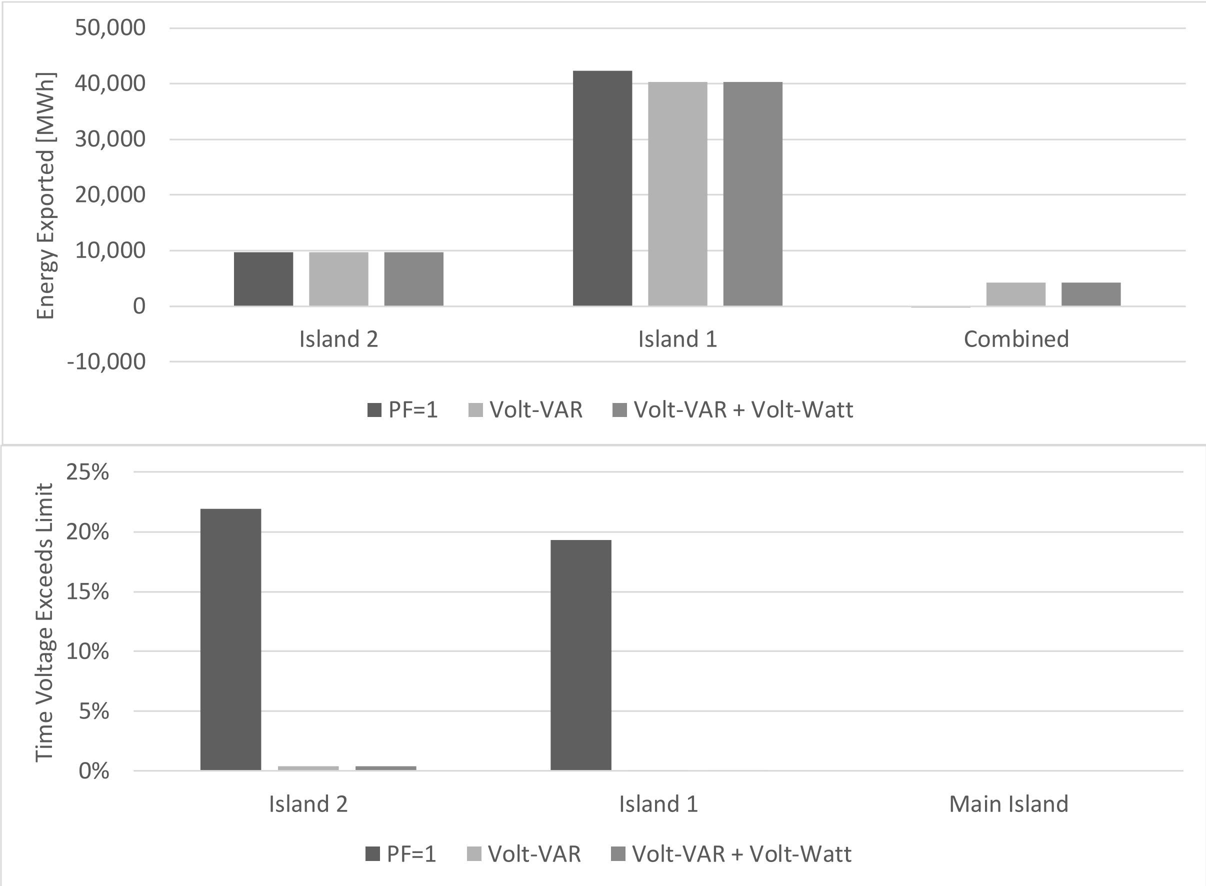

Fig. 6. Energy exported from each island as well as amount of time voltage limits are violated at each location with a 38kV voltage regulator installed.

5. CONCLUSIONS

This paper presented the high-level proposal of interconnected microgrids in two interconnected islands which in turn are interconnected to a larger island main grid. The proposed microgrids will rely on 10MWh BESS and 15 MW PV generation and will provide:

- 41% reduction of the overall diesel consumption in Island 1 for total loss of subtransmission supply.
- 35% reduction of the overall diesel consumption in Island 2, for a total loss of subtransmission supply.
- 42% of reduction of the overall diesel consumption in the minigrid containing Islands 1 and 2, assuming both are still connected to one another, should there be total loss of subtransmission supply from the main island.
- 54% reduction of the overall energy consumption in Island 1 during blue sky operation.
- 40% reduction of the overall energy consumption in Island 2 for blue sky operation.
- 56% reduction of the overall energy consumption in the minigrid of Islands 1 and 2, for blue sky operation.

A time-series voltage and loading power flow study was conducted for 8760 hours (one year) to illustrate the need for system upgrades and smart inverter controls. It was found that solutions are possible to bring the system towards high penetration of renewable energy. As the team plans implementation of the proposed microgrids, it is expected the proposed innovations will benefit underrepresented and vulnerable communities and the industry at large.

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