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Using Wind and Hydro Power to Sustain the Off-Grid Power Supply for a 50' Cruising Sailboat

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Abstract

Cruising sailboats operate with a power requirement modest enough to operate mostly or completely on renewable energy technology sources. Cruisers without renewable energy systems use the vessel's diesel engine to charge the boat's batteries; if the systems are operated at anchor, this dramatically decreases the time before the engine needs major overhaul. System users estimate a diesel engine can run approximately 8,000 hours underway before needing major overhaul, whereas operating 500 hours at anchor produces similar wear and tear on engine pistons. Although renewable energy systems have a high initial capital cost, these systems can provide the vessel's electrical system with sufficient power without additional wear and tear on the vessel's diesel engine. This research outlines the power requirement for a 50-foot ocean cruising sailboat, the potential wind and hydro power that can be harvested from a popular cruising route from the United States around Puerto Rico, and the cost of installing this system on the vessel. A wind and hydropower renewable energy system is designed to meet the energy requirement for 95% of the voyage.

Keywords: Maritime; Renewable energy; Wind power; Hydro generator; Off-grid

Introduction

The majority of cruising yachts are designed for short cruises and require several system upgrades in order to meet the energy demands of daily living [1-10]. Energy can be generated from an onboard diesel engine, however this is not a noise-free or sustainable energy solution. A renewable system is needed to allow the vessel to operate off-grid with a minimal environmental footprint so the cruiser can visit protected environmental habitats that are excellent for diving and snorkeling [1,5,6,11,12].

A cruising route that departs from Fort Lauderdale, Florida, United States, travels around the south and western coasts of Puerto Rico, and ends in St. Thomas, US Virgin Islands [13], was selected for this analysis. The length of stay at anchor was determined by activities available at each location, including diving/snorkeling sites and beaches. An objective function was developed to determine how much of the vessel's energy requirement can be produced using commercially available hydro generators and wind turbines.

Materials and Methods

Hydro and wind generators were selected based on the vessel's size, boat speed, and wind speed conditions expected for the selected route [2-6]. Forecasted power generation from wind turbines and hydro generators is compared to the vessel's overall energy requirement. Table 1 gives the nautical miles sailed from the port or anchorage to the proceeding destination, as well as hours under sail during the passage, and hours on location at anchor.

Port/Anchorage	NM sailed	Hours Under Sail	Hours at Anchor
Lauderdale Marina, Florida	74.3	10.7	49
Old Bahama Bay Marine, Bahamas	961.9	155.4	85.3
Mayaguez Bay, Puerto Rico	44.6	8.7	60.7
Sardinera Anchorage Inlet, Puerto Rico	56.3	9.4	86.3
Boqueron Bay Anchorage, Puerto Rico	24.5	11.1	61.6
Guanica Anchorage, Puerto Rico	46.9	9.8	85
Playa de Salinas Anchorage, Puerto Rico	46.6	8.8	38.3
Naguabo Town Dock, Puerto Rico	46.7	5.9	37.2

Culebra, Puerto Rico	32.6	7.2	90.1
American Yacht Harbor Marina, St. Thomas	38.5	N/A	58.8
Total	1255.1	226.8	652.3

Table 1: Route for analysis, departing from Fort Lauderdale, USA and ending in St. Thomas, USVI.

The listed parameters were determined using the nautical weather routing tool FastSeas [2]. The tool has adjustable features for calculating boatspeed for a sailing vessel, based on boat-specifics sailing angles, and wind and current conditions for a particular route. FastSeas' data is determined by analyzing current weather forecasts considering wind speed, wind gusts, wind direction, ocean current speed, and ocean current direction; projections are a maximum of two weeks for user-entered latitude/longitude positions.

Analysis Results and Discussion

Electronics commonly installed on a 50-foot cruising sailboat are included in the energy demand. This study identified the electronics used during each hour of the day, both at anchor and under sail. Table 2 displays the power and energy requirements per device for each condition. The energy requirement was provided as an input to the route based on the FastSeas weather and boatspeed output during the last two weeks in November 2018.

Device	Watts	Use at anchor	Use under sail	Daily Watt-hrs Usage
Radar	43.2	0	1	1036.8
Chart Plotter	20	0	1	80
Transducer (depth & temperature)	600	0	1	0
LED Interior lights (up to 12)	7	1	1	210 / 35
Refrigerator/Freezer	38.4	1	1	921.6
Fans	3	1	1	102 / 18
Bilge Pump (electric)	100.8	1	1	67.2 / 115
Battery Monitor	1	1	1	24
Watermaker	1500	0	1	1500
Masthead Tricolor LED light	1.8	1	1	23.4
Laptop Computer	1.2	1	1	10.8 / 21.6
Printer	30	1	1	30
SSB Radio	4.8	0	1	115.2
VHF Marine Radio	0.5/5	1	1	12
Anchor Windlass	18	0	1	18
Toilet (electric)	120	1	1	120
Jib Furler	300	0	1	5
Induction Cooktop	2400	1	1	2400

Table 2: Daily power requirements while at anchor and under sail.

Electronic devices used aboard the cruising vessel were selected based on user testimonials [1,7]. Examples of high power-drawing devices include the watermaker, which converts salt to fresh water and uses 1500 watts, and the induction cooktop which uses 2400 watts. The devices do not operate continuously, similar to most of the electronic devices aboard.

For example, the watermaker produces 20 gallons of water and is estimated to operate twice a day, for 30 minutes at a time. The induction cooktop requires power three times a day for 20 minutes each to prepare breakfast, lunch, and dinner. If conservation of power is a focus while under sail or at anchor, these devices could be operated less. The devices are an integral part of the energy requirement for the analysis.

The energy usage requirement both at anchor and under sail is plotted between the hours of 0000 and 2400 in Figure 1. Energy peaks occur when the induction cooktop and/or watermaker are operated.

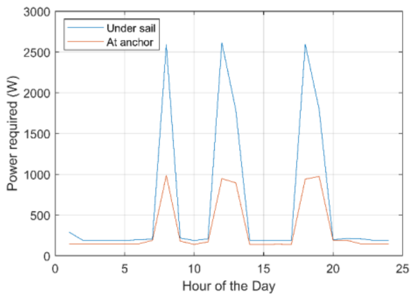

Figure 1: Daily energy requirement while under sail and at anchor.

The combined energy requirement includes time spent at anchor and under sail for the entire voyage. This information is presented in Figure 2, which provides a basis for how much energy must be generated to meet the needs of the cruiser.

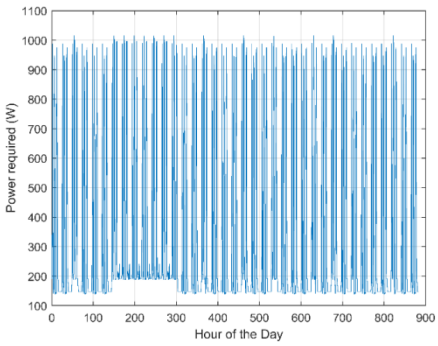

Figure 2: Energy requirement.

Energy Generation

The energy requirement ranges from 200-1015 watts per hour. The proposed energy system aboard is designed to meet these requirements. Commercially available renewable energy generation systems are selected, and the quantity of energy these devices generate during the voyage is calculated. These values are based on commercially available information from manufacturers and average wind velocities at ports, anchorages, and along the route at sea [2-4].

Hydrogenerator

The hydrogenerator selected can fit on the 50-foot cruising sailboat, and operate during the expected boatspeeds for the route, which vary between 2.7 -7.9 knots. Commercial availability and user testimonials were also considered [1,7,10]. The optimal hydrogenerator will start to generate usable electricity at relatively low boat speeds in accordance with the expected conditions of the voyage [2]. The hydrogenerator is designed for use while the boat is moving forward, it will not deploy while at anchor. The device is affixed to the vessel's transom and should be deployed when the cruiser is underway.

Watt and Sea's Cruising 600 hydrogenerator was selected as the most appropriate generator to support the onboard energy demand on the sailboat. The output curves of the Cruising 600 show that the device begins to generate an electricity at a boat speed of 1.1 knots. The device can generate up to 600 watts an hour at a 15 knots boatspeed, at which the device reaches its limit. The 280 mm propeller has been selected for use with this device because of the estimated speeds along the route. 280 mm is the largest available propeller size for the Cruising 600 [5]. During boat speeds of 15 knots and greater, the hydrogenerator should be raised as it is not designed for use under higher speed conditions. The expected watts per hour generated by the Cruising 600 is shown in Figure 3, which is plotted to show the maximum expected boatspeed of 8 knots on this route [5].

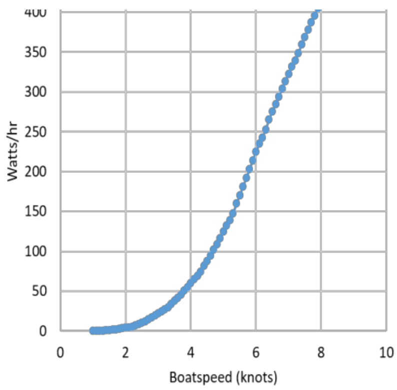

Figure 3: Watt and Sea's Cruising 600 hydrogenerator output.

Wind turbine

The selected wind turbine, Hamilton Co's Ferris 200 model, is designed to be suspended from the rigging. The turbine generates electricity both at anchor and under sail, but only under windspeeds of 6 knots and greater [6]. The more wind present, the more electricity the wind turbine generates, up to wind speeds not specifically detailed by the manufacturer, but expected maximums of 20 knots [6]. The manufacturer's output information was estimated from the device's published output curve and plotted up to windspeeds of 20 knots, as shown in Figure 4 [2,6].

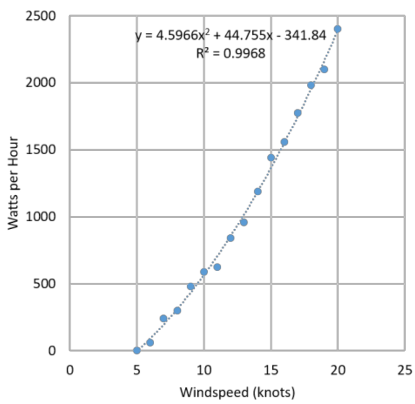

Figure 4: Hamilton Ferris 200 Wind turbine power output.

Generated power

The proposed system determines the output for two Watt & Sea Cruising 600 hydrogenerators and two Ferris 200 wind turbines. The plot of power generated throughout the voyage is shown in Figure 5.

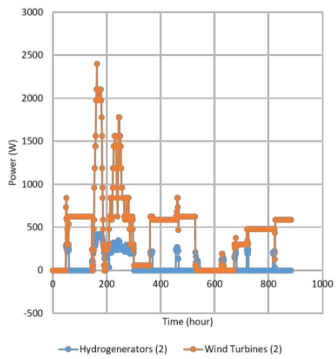

Figure 5: Generated power.

Time spent at anchor with less than 6 knots of wind is the period of time where no energy is generated. Since the hydrogenerator is not usable at anchor, and the wind turbines do not produce outputs at windspeeds below 6 knots, this is the period where the system cannot provide sufficient energy to meet the demand.

Typically, harbors have decreased wind speeds compared to open water due to reduced air circulation and construction. Anchorages appeal to boaters because of protection from weather, wind, and waves. The surrounding area account for the lower wind speeds and watts generated by the wind turbine while at anchor. Average power generated by the Ferris 200 while at anchor for cities along the route are shown in Table 3.

Anchorage	Average Windspeed (kts)	Average Power Generated (W)
Ft Lauderdale	5	0
West End	11	624
Mayaguez	6	60
Mona Island	10	588
Cabo Rojo	11	624
Playa de Guanica	5	0
Playa de Salinas	5	0
Naguabo	8	300
Culebra	9	480
St. Thomas	10	588

Table 3: Power generated by the Ferris 200 wind turbine while at route locations.

The energy requirement and energy generated while at anchor are compared in Figure 6. The watermaker and induction cooktops remain the highest energy consuming devices. The energy demand exceeds the energy generated when the boat is at anchor in a harbor with less than 6 knots average windspeed.

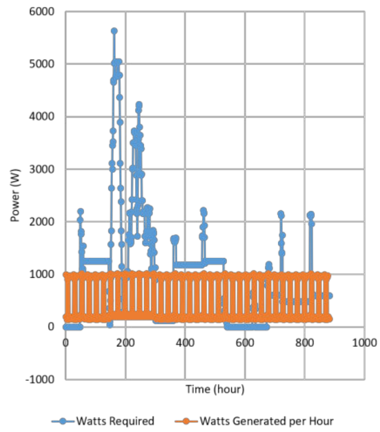

Figure 6: Watts required, plotted in blue, and watts generated, plotted in orange.

Conclusions

The proposed energy system generates more energy than is required for 836 hours of the 883 hour voyage, which is 94.7% of the time. The energy requirement is unmet for the remaining 5.3% of the time. The main energy deficiency occurs in Fort Lauderdale while the vessel is in a harbor and before the vessel has undertaken passage and is able to deploy the hydrogenerator. At this location, the average windspeeds is less than 6 knots, which is below the threshold for the Ferris 200 to generate power.

This analysis suggests that further research is needed to determine if the unmet 5.32% of the voyage time could be met with other renewable energy technologies. By adding a battery and/or a photovoltaic energy generation system, the unmet energy requirement could be dramatically decreased. The goal of the system modification is to target the time the vessel spends at anchor in locations that have insufficient wind resource to generate energy. Additionally, the route cities could be analyzed for PV system sustainability based on hours of sunlight, time of year, and required tilt of the panels based on practical considerations aboard the vessel.

Declaration

The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof. Reference to specific commercial products does not constitute or imply its endorsement, recommendation, or favoring by the U.S. Government. The authors declare this is a work of the U.S. Government and is not subject to copyright protection in the United States. This article was cleared with case number 88ABW-2019-1006.

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