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Integration of wave power in Haida Gwaii

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Remote communities, such as Haida Gwaii, Canada, often have high energy costs due to their dependence on diesel fuel for generation. Haida Gwaii's lengthy coastline, exposed to the northeast Pacific Ocean, provides opportunities for capturing wave energy to potentially reduce energy costs. A mixed integer optimization model of the Haida Gwaii network is used to develop an operational strategy indicative of realistic operator behaviour. Two offshore locations are analyzed where the annual mean theoretical wave power is 42 kW/m and 16 kW/m, respectively. Results from both models show that the wave energy resource in Haida Gwaii has the potential to reduce the operational cost of energy and carbon dioxide emissions. A maximum allowable capital cost, above which the overall cost of energy would increase, is determined for various levels of installed wave capacity. Offshore transmission cost estimates are included, as well as the effects of the offshore transmission distance.

1. Introduction

Electricity generation is an issue of particular concern to remote communities where electricity costs are high [1]. Haida Gwaii, Canada is such a community, where the system average cost of electricity production in 2006 was $0.26 (CAN)/kWh [2]. Renewable energy sources might be able to mitigate these high energy costs, with wave power of particular interest to communities, such as Haida Gwaii, that have access to the ocean. Estimates from the National Research Council suggest that an annual mean wave power of 45–54 kW/m is available off the western coast of Haida Gwaii [3].

Although great potential exists for electricity generation from renewable sources, intermittency and high capital costs can reduce or eliminate the economic benefit [4]. Generation responsiveness plays a large role in determining the level of intermittent capacity that can be integrated in a grid [1]. Short term fluctuations in power, often in combination with a must-take operating policy [5], force traditional dispatchable generators to change their output to meet the remaining load. This can result in a reduction in efficiency and increased maintenance [1]. In addition, an increase in system balancing reserves may be required with the addition of intermittent generation, thereby further increasing system costs [6].

The purpose of this study is to investigate the technical, economic and emissions impacts of integrating wave power into the Haida Gwaii electrical system. The current network consists of two independent grids, which could potentially be linked. Wave power data are used in combination with an optimization model that minimizes system operational cost. Optimization results are used to develop an operational strategy indicative of operator behaviour. The effects of wave power integration into the Haida Gwaii generation system are then analyzed using the proposed operational strategy.

2. Potential for wave power in Haida Gwaii

Wave resource data for five locations near Haida Gwaii are available from the Department of Fisheries and Oceans (DFO) Canada [7]. Data are provided by buoys operated by the Meteorological Service of Canada; their locations are represented by circles in Fig. 1. Hourly data from January 2000 until June 2009 are utilized. Buoy data of interest include the significant wave height, H_s, and peak period, T_p. T_p is the period associated with the most energetic wave at a specific location [8], while H_s is represented by Eq. (1),

$$H_s = 4a_{rms} = 4\left[\frac{\left(\sum_{i=1}^{n} h^2\right)}{n}\right]^{\frac{1}{2}} \tag{1}$$

where h is the displacement of the water surface from the mean position calculated from n measurements at equal time intervals, and a_{rms} is the root mean square of h [9].

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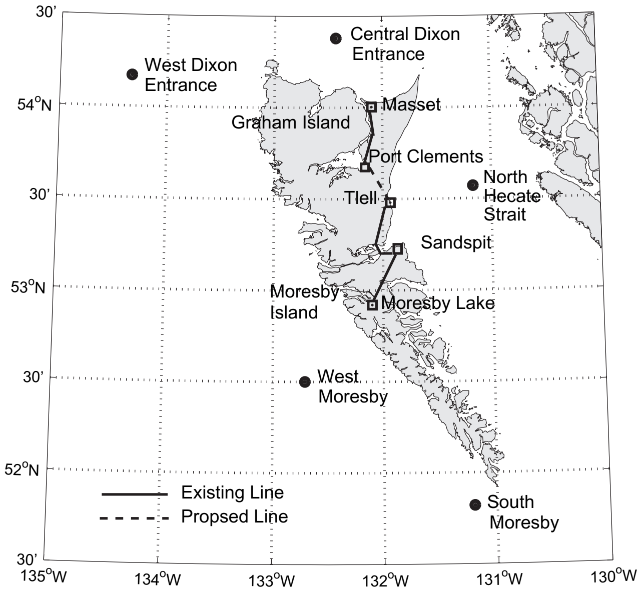

Fig. 1. Map of Haida Gwaii identifying wave buoy locations with circles and population centres with squares.

Theoretical wave power per unit wave crest, P, was calculated for each buoy location using Eq. (2),

$$P = \frac{\rho g^2 H_s^2 T_e}{64\pi} \tag{2}$$

where ρ is density of the fluid, g is gravitational acceleration and T_e is the energy period [9]. The energy period is equal to the period of a single sinusoidal wave with the same energy as the sea state [3,9]. In accordance with similar wave resource analyses, it is assumed that $T_p = \alpha T_e$ [3], where the value $\alpha = 0.9$ is chosen for this study [3].

The theoretical wave power resource is largest for the buoys located off the west coast of Haida Gwaii. Using Eq. (2), the annual mean wave power for a typical year is 41–43 kW/m for the West Dixon Entrance, South Moresby and West Moresby locations, while it is 16 kW/m and 11 kW/m for the Central Dixon Entrance and North Hecate Strait locations, respectively (see Fig. 1 for buoy locations). These findings are similar to those of Cornett [3].

These wave buoy data sets vary in the amount of usable information provided. To be usable, the data must not only be present but classified as *good* or *acceptable* by DFO. A *coverage value*, ζ, was calculated for each month of buoy data, a method which was adopted from Dunnett [10]. Value ζ represents the percent of usable data in each month:

$$\varsigma_{\mathrm{loc,m,y}} = \frac{h_{\mathrm{loc,m,y}}}{24 \times d_{\mathrm{m,y}}} \tag{3}$$

where $h_{\mathrm{loc,m,y}}$ refers to the total hours of usable buoy data in a given location in month m and year y, and $d_{\mathrm{m,y}}$ refers to the actual number of days in the given month and year. Months with coverage values below 90% are excluded from the analysis.

Manufacturer performance data are used to convert hourly wave data to output power from a wave energy converter (WEC). The Pelamis device was selected as it has seen extensive sea trials and was deployed in the first commercial wave farm [11]. According to Pelamis Wave Power (PWP), specifications for the 750 kW capacity Pelamis device were derived using an experimentally verified numerical model that assumed a two-parameter Pierson–Moskowitz spectrum as input and took into account design constraints and machine efficiency [12]. Period was presented by PWP in the form of T_{pow}, and it is assumed that $T_{\mathrm{pow}} = T_e$ [3]. Hourly wave power is calculated from buoy measurements of H_s and T_p by interpolating between values in the performance data table.

Potential locations for a WEC are assessed based on average annual capacity factors (CFs) and relative proximity to the existing grid. CF is defined as the total output energy from a device divided by the potential output energy if the device had been continuously operating at full capacity. A high CF reduces the number of devices required to reach a given level of energy output, resulting in a lower capital cost.

Hourly outputs of wave power determined from buoy data [7] and the Pelamis power matrix [12] are used to determine monthly CFs for all years of data. The average monthly CF is then determined for each location followed by the average annual CF (Table 1). The highest annual capacity factors are seen at the South Moresby, West Moresby and West Dixon Entrance locations.

The distance from the buoy location to shore and the distance on shore to the nearest grid connection point was also determined (Table 1). For the West Dixon Entrance and South Moresby locations, these distances are significantly longer than the other locations. When calculating the transmission distance, it is assumed that no overland transmission lines are allowed in the Gwaii Haanas National Park Reserve.

3. Optimal integration of wave power in Haida Gwaii

3.1. Existing network

The existing generation and transmission system, discussed in detail in Boronowski [13], is characterized by two separate electrical grids operated by BC Hydro, namely the North and South grids [14] (Fig. 1). The majority of transmission in Haida Gwaii is 25 kV lines [15]. Exceptions include a 50 km line linking the Moresby Lake hydro facility to the South grid.

Electricity in Haida Gwaii is supplied from a combination of diesel generating units and small hydro. The North grid peak load of approximately 5 MW is met by seven diesel generating units that comprise the 11.4 MW capacity Masset Diesel Generation Station (Masset DGS) (Table 2). Peak load for the South grid is slightly higher than that of the North, at approximately 5.5 MW. The South grid is powered primarily by the 5.7 MW capacity independent power producer (IPP) owned hydro facility on Moresby Lake. Back up power for the South grid is supplied by the BC Hydro facility at Sandspit, Sandspit DGS, which is also composed of seven diesel generating units varying in size from 0.85 MW to 2.5 MW for a total capacity of 9.15 MW (Table 2). In a typical year, 80% of the energy consumed by the South grid is supplied by the IPP. [14]

Table 1
Wave energy potential by location.

Buoy Location	Average annual CF	Distance to shore (km)	Distance on land to grid (km)	Total distance (km)
West Dixon Entrance	25%	80	60	140
Central Dixon Entrance	10%	40	3	43
North Hecate Strait	9%	50	1	51
South Moresby	28%	120	20	140
West Moresby	26%	45	17	62