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Evaluation of small wind turbines in distributed arrangement as sustainable wind energy option for Barbados

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Abstract

The island of Barbados is 99% dependent on fossil fuel imports to satisfy its energy needs, which is unsustainable. This study proposes a 10 MW distributed wind energy scheme using micro wind turbines (WT) of horizontal (HAWT) and vertical axis (VAWT) configurations. These units are rated less than 500 W, and the scheme is hereafter referred to as mWT10. mWT10 is compared to the proposed 10 MW medium WT farm by the Barbados Light & Power Company (BL&P). The economic bottom line is the levelized cost of electricity (LCOE). The results highlight the BL&P proposal as the best economic option at BDS$0.19 per kWh, while that of both mWT10 configurations exceeds the conventional cost of BDS$0.25 by two to nine times. This is attributed to significantly higher relative installation and operational costs. However, the financial gap between mWT10 LCOE and the retail price of electricity is much smaller due to a large fuel surcharge passed on to each customer. Annual additional benefits of using wind energy include: greenhouse gas emissions savings of 6–23 kt of carbon dioxide; and anavoided fuel costs of BDS$1.5–5.3 million.

The distributed mWT10 using HAWTs competes directly with the BL&P farm, however, it provides these benefits without the visual or ecological impacts of the larger machines. Conversely, VAWTs have features that favour a visually discrete and widely repeatable scheme but suffer relatively high costs. Therefore, this study illustrates the great potential of small wind turbines to be competitive with conventional wind farms, thus challenging the small wind industry to meet its potential by producing reliable and robust machines at lower cost.

Keywords: Engineering for sustainable development; Renewable energy; Wind energy; Micro wind turbines; Sustainable energy systems; Distributed generation

1. Introduction

The 431 km^2 Caribbean island of Barbados is located at 13°04′, −59°29′ (Grantley Adams International Airport, GAIA) and is 99% dependent on imported fossil fuels to meet its energy needs, half of which are used in electricity generation. This dependence on a non-native, non-renewable fuel, which decreases in availability and increases in price every year, leaves Barbados and other small states in a precarious position. Moreover, Barbados must trade internationally using foreign exchange obtained from its reserves. Consequently, large expenditures on fuel put a strain on these savings.

The privately owned Barbados Light & Power Company (BL&P) is the original and sole electricity service provider. In 2005, there was a peak demand of 154.20 MW, supplied by 239.10 MW total installed capacity [1]. Customers are charged a base energy price and a fuel adjustment clause (FAC), which allows BL&P to recoup some expenses from the increasing fossil fuel costs. In 2005, the FAC averaged BDS[1]$0.17 per kWh.

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[1] The Barbados dollar, BDS$, is used throughout unless otherwise specified, at an exchange rate of US$1.00 to BDS$1.98 and €1.00 to BDS$2.54.

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The BL&P conventional generating fuel mix of heavy oil, Diesel and kerosene releases 0.77 kg of carbon dioxide (CO_2) per kWh, resulting in the emission of 760 kt of CO_2 in 2005.

The Intergovernmental Panel on Climate Change (IPCC) indicates that the increase in global CO_2 emissions since the beginning of the industrial age has resulted in the highest concentration in the last 420,000 years and likely in the last 20 million years [2]. World Data Center for Greenhouse Gases (WDCGG) measurements taken at the most upwind location in Barbados of Ragged Point show an atmospheric concentration of 380.7 parts per million (ppm) CO_2 in December 2005. Therefore, climate change on a global state has effects on Barbados, and thus, the issue is more whether mankind can afford to continue burning fossil fuels than how much is actually left to be consumed [3].

Herman Daly argues the concept of quasi-sustainability [4], where a renewable alternative is developed simultaneously with the exploitation of a non-renewable such that when the latter reaches the end of its life, the former is in a position to substitute. Practically however, a historical lock into fossil fuel based generation has implied a lock out of generation by other methods, such as renewables [5]. Decommissioning of aging generating plants, most recently in 2004 by BL&P, provides the opportunity necessary for renewable energy converters to be implemented [6]. The Government of Barbados (GoB) has a target of 40% of its energy needs to be met by renewable sources by 2025 [7].

Barbados benefits from north easterly trade winds, allowing wind energy conversion technologies to be technically feasible. The wind turbine (WT) axis of rotation may be aligned vertically, for vertical axis WTs (VAWTs) or, more commonly, horizontally, for horizontal axis WTs (HAWTs). The full range of WTs covers many power levels, from large, multi-megawatt utility scale machines to micro machines of less than 100 W for battery charging.

The term "intermittent" is used interchangeably with "variable" to describe the energy output of wind and other renewable energy converters. However intermittent sources start and stop unexpectedly, whereas variable ones have predictable, though non-constant, output [8]. Furthermore, wind and other renewable energy based electricity systems have fixed and dependable fuel costs, as the natural resource is fully assessed at the time of deployment, whereas fossil fuel based systems depend on a price variable input. This is illustrated by the inclusion of the variable FAC to the base energy cost, yielding a fluctuating retail energy price.

BL&P recently concluded the stakeholder consultation phase of a 10 MW medium WT (MWT) farm in the Lamberts East area of the northern most parish, St. Lucy. The BL&P proposal would consist of eleven 900 kW machines with rotor diameter up to 56 m on towers up to 55 m above ground level (AGL), arranged in line along a topographical ridge. The farm would be located 1.50 km inland from the windward, east coast. The farm will occupy a strip of land of 1.50 km in length. The justification for the scheme is deferral of CO_2 emissions [9], and it is expected that the farm would produce 30.03 gigawatt hours (GWh) annually.

The alternative 10 MW scheme proposed herein capitalizes on the benefits of distributed generation and the flexibility of small machines. The scheme would utilize many micro WTs with rating <0.50 kW [10] each, (mWT10). It is envisioned that this initiative be spearheaded by BL&P, mounted on their utility poles, operating at a hub height of 10 m without the option of providing back-up energy. Both schemes constitute 6.49% of the 2005 peak demand. mWT10 is evaluated using micro HAWTs and VAWTs.

mWTs are not generally deployed in utility scale initiatives, due in part to low investment devoted to making these machines competitive on a feature and reliability basis. Thus, utility skepticism and low confidence in the ability of the machines to deliver as advertised detracts from mWT10. Consequently, this study gives insight into what is possible, if the appropriate investments in reliability, quality and performance were made. The International Energy Agency (IEA) has recognized the current industrial deficiencies and large potential and is seeking to bridge this gap [11]. Recognizing the aforementioned technological shortcomings, where possible, WTs accredited by the UK Department of Trade and Industry (DTI) Low Carbon Buildings Programme, formerly the Clear Skies programme, are used.

2. Wind resource assessment

The wind site evaluation technique used is given below:

(1) Wind speed measurements were grouped by the number of occurrences in a particular wind speed class to determine the frequency distribution (Fig. 1).
(2) A Weibull probability distribution was fitted to the frequency graph (Fig. 2), and the average and most probable wind speeds are derived, all using the following equations [12].

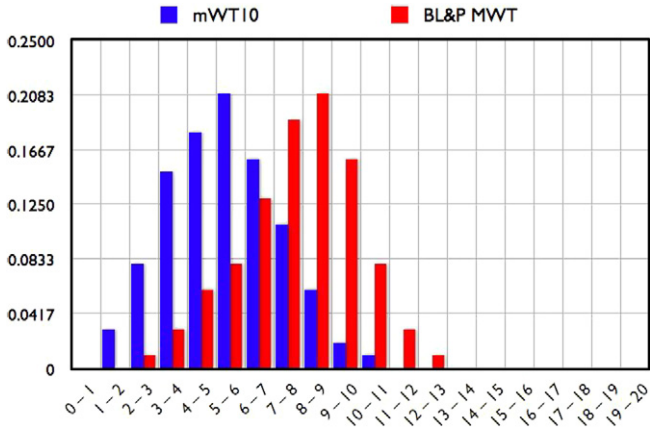

Fig. 1. Frequency distribution of CIMH and BEI data.