Optimized Design of a Hybrid PV-Wind-Diesel Energy System for Sustainable Development at Coastal Areas in Bangladesh

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Power generation capacity of Bangladesh needs to be enhanced to support the rising electricity demand. Bangladesh has predominantly used fossil fuel generators for the past decades. Saint Martin’s Island and Kuakata are two significant areas that lie at or near the coast of Bangladesh with an average annual solar radiation of 4.81 and 4.65 kWh m⁻² day⁻¹, respectively. The monthly average wind speeds at a height of 25 meters are 4.79 and 4.54 m s⁻¹, respectively. Considering this data and the benefits of the optimized hybrid systems, HOMER (Hybrid Optimization Model for Electric Renewable) is used to optimize a system for each of these areas. The costs of energy found from the proposed optimized PV-wind-diesel Hybrid Energy system for Saint Martin’s island and Kuakata are 0.393 and 0.392 USD kW⁻¹ h⁻¹, respectively, the net present cost (NPC) also has been evaluated as 168,767,831 USD which are quite reasonable with respect to the present situation in Bangladesh. The major objective of this proposed optimized design is to supply the maximum load demand using renewable sources with the minimum cost of energy (COE) and reduce the burning of fuel and also reduce the emission of CO₂. The proposed energy system is able to meet 67.3 and 62.3% load demand using renewable sources, which helps to reduce the GHG (Green Houses Gas) emission by 67 and 64% for Saint Martin’s island and Kuakata, respectively when compared to a diesel system. Total load served throughout the year is 33,611 kWh, which is 16% higher than the previously designed system with approximately equivalent COE. © 2016 American Institute of Chemical Engineers Environ Prog, 36: 297–304, 2017

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INTRODUCTION

In recent years, due to rapid technological development, declining cost of equipment needed for renewable energy systems, government economic incentives, and pollution free characteristic of resources, significant worldwide attention has been directed toward power production from the renewable sources, such as PV, wind, biomass, geothermal, ocean wave, tides, etc. Many countries have set up or demonstrated large, small and micro power generation systems using exploitable renewable resources [1,2]. In Bangladesh, to establish the use of alternative and sustainable energy sources, several NGOs and government organizations are working continuously to develop the solar and wind power sector. In 2004, a survey carried out by the Local Government Engineering Department (LGED) under the Sustainable Rural Energy (SRE) program recorded that, Saint Martin’s island (situated just south off the coast of Cox’s Bazar) houses 778 families with an annual energy demand of 359 MWh. To meet this demand, the Bangladesh Power Development Board (BPDB) installed a 30 kW diesel generator, which is currently out of service [3]. Therefore, it is evident that a more suitable solution is needed to fulfill the demands of these areas.

The annual average solar radiation is similar throughout the coastal region of Bangladesh. Average annual global solar radiations at Saint Martin and Kuakata are 4.81 and 4.65 kWh m⁻² day⁻¹, respectively, and monthly average wind speed at 25-m height are 4.79 and 4.54 m s⁻¹, respectively. Given that, the solar radiation and wind speed data is consistent, it should be enough to produce electricity to meet the energy demand in coastal areas by setting up off-grid hybrid systems. Integration of multiple renewable energy sources with equipment presently available may possibly help to improve the load factors, debilitate individual fluctuation and provide higher reliability and operational flexibility while lowering production, maintenance and replacement costs. It also reduces the pollutant emission to the atmosphere. For most of the cases, this combination behaves, like a full complement system between various energy sources. This is known as a hybrid system [4]. Because the hybrid system contains various costly components needed for renewable energy systems, perfectly optimized system designs are needed to lower net present cost (NPC) and the cost of energy (COE).
Several hybrid system optimization techniques and simulation programs have been developed so far. Because of the incorporation of non-linear components with many optimization parameters and failure of classical methods, genetic algorithms based design and operation control techniques are used for solving complex problems [5]. Computer aided simulating programs, such as HYBRID-2 developed by the National Renewable Energy Laboratory (NREL) from USA and TRNSYS by the University of Wisconsin from USA were developed to simulate the hybrid system [6]. Though HYBRID-2 is unable to optimize the system, a very accurate simulation of a hybrid model is possible with this tool. Initially, TRNSYS was developed for thermal system simulation and later, PV system was included with TRNSYS to simulate the hybrid system. However, this tool is also unable to optimize the system [7].

The operation and control of PV-diesel hybrid system is achieved through an artificial neural network. For optimization purposes, a dispatch strategy has been applied by setting a starting and stopping point of the diesel generator [8]. To optimize a solar-wind hybrid system, iterative and probabilistic calculation techniques considering the loss of power supply probability (LPSP) were proposed. Using these techniques, the optimized system with minimized system cost was designed [9].

Worldwide several studies have been done on hybrid system optimization techniques and developed simulation programs for power supply in off-grid area [10]. The major drawback associated with wind and solar is their unreliable nature, site dependence, dependence on weather and climatic changes, which make the optimization process more complex and demands better optimization technique [11]. Yang et al. proposed iterative and probabilistic calculation techniques considering the loss of power supply probability (LPSP) to optimize a solar-wind hybrid system [12]. In another research study carried by Kellog et al. for unit sizing and cost analysis of an off-grid wind-solar-PV hybrid system proposed simple numerical algorithms [13].

HOMER (hybrid optimization model for electric renewable) simulation program was developed by NREL, USA to optimize the micro-power hybrid system using a kinetic battery model [16]. This model is widely used as a hybrid system optimization program and continuously updated with the new features. Technically, HOMER always finds the most energy efficient combination of hybrid system based on the energy source models, load profile, data of solar radiation, wind speed, fuel price, and component details. It also performs sensitivity analysis to visualize the impact on COE by varying parameters (wind speed, solar radiation, fuel price, maximum annual capacity shortage, and hub height) [17]. In 2012, for Saint Martin Island, an optimized design has been carried out using HOMER, while this author’s efforts were concentrated to reduce the COE. They were able to extract only 31% load demand (31% renewable fraction) using