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Feasibility and sensitivity analysis of an off-grid micro hydro –photovoltaic–biomass and biogas–diesel–battery hybrid energy system for a remote area in Uttarakhand state, India

Ankit Bhatt [a,*], M.P. Sharma [b], R.P. Saini [b]

[a] Graphic Era University, Dehradun 248002, Uttarakhand, India
[b] Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee 247677, Uttarakhand, India

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ABSTRACT

The aim of this paper is to study techno-economic feasibility of microhydro–photovoltaic–biomass and biogas–diesel–battery hybrid energy system (HES) in off-grid mode for a rural area in Uttarakhand state, India. The considered HES is designed for energy access in 5 un-electrified villages. Size optimization and sensitivity analysis of considered system is performed by using HOMER software in order to meet the electricity requirements of study area. The selection of optimum configuration is based on the lowest value of cost of energy (COE) and net present cost (NPC) along with the maximum value of renewable fraction (RF) and lowest harmful emissions (CO_2). By considering economy and environment as the main concerns, comparative analysis of four different types of models is presented here. Based on sensitivity analysis, 3 configurations out of four different models are selected. By considering economy and environment as the main driving factors, one configuration out of three configurations, is selected as the optimum configuration for the study area which comprises total NPC $5,33,654, COE $0.197/kW h, RF 94% and CO_2 emission 15,930 kg/yr.

Contents

* Corresponding author. Tel.: +91 9557627287.
E-mail address: bhatt.ankit.23@gmail.com (A. Bhatt).

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1. Introduction

Globalization, development of new technologies and higher energy consumption have increased the energy demand very rapidly in the past several years. In present scenario, fossil fuels and nuclear energy are the main sources of generating electricity across the world. But these sources are responsible for environmental pollution therefore renewable energy sources are announced as future source of green electricity. Renewable energy resources are environment friendly and in exhaustive. These resources contribute almost 13.5% of the global energy demand.

Rural electrification plays an essential role in energy access to remote areas. Also, energy supply to such areas can be used to operate machineries of agricultural applications. Presently, around 200 million people of rural areas of India are not connected to the grid. More than 80,000 villages are not electrified because it becomes difficult to electrify them by grid electricity due to high capital cost, poor voltage regulation and low load factor [1]. Therefore, electrification of remote and non- electrified areas is a big challenge which requires cost effective approaches that can supply power to these areas.

For such remote areas where grid based power is not available, off- grid HES can competitively supply the power. The introduction of diesel generator (DG) decreases the dependency on solar or wind component which reduces the operating hours and running costs of diesel generator [2]. Introduction of battery storage also limits the diesel generators from maximum start/stop cycles which reduce the fuel consumption [3,4]. In past years, it has been observed that the HES has become the most reliable system for isolated areas [5]. The main objective of an HES is to attain fuel saving and provide reliable power supply. To overcome the alternating nature of some renewable energy resources like solar and wind, it is necessary to combine two or more power generating sources with battery/diesel/battery-diesel so that system performance can be improved.

A hybrid energy system consists of two or more energy systems, an energy storage device, a controller and a power conditioning unit [6]. This system can be grid connected or in off-grid mode. For rural electrification HES can be classified as: off-grid distribution system, off-grid based on direct supply and grid connected mode. The size optimization of HES has been carried out by several researchers using economic analysis in terms of different parameters like life cycle cost, NPC and COE of the system [7–10].

Lanre et al. [11] determined the economic feasibility of PV/diesel/battery hybrid system based on NPC, COE and RF. Fazia et al. [12] investigated the performance of hybrid PV/wind/diesel/battery configuration based on hourly measurement by using HOMER software and concluded that about 69% of the fossil fuel can be saved by using the proposed hybrid configuration. Integrated sizing and scheduling of wind/PV/diesel/battery based hybrid system was proposed by Andre et al. [13]. They formulated mixed-integer linear programming to model system behavior. Castellanos et al. [14] described the design optimization and techno-economic analysis of off-grid IRES. For electricity generation they used anaerobic digestion with biogas CHP and photovoltaic. Sen and Bhattacharyya [15] proposed HES with four renewable resources, namely, SHP, SPV systems, wind turbines and bio-diesel generators. By using HOMER, they identified the optimal off-grid option and compared it with conventional grid extension. Gonzalez et al. [16] proposed the optimal sizing of hybrid grid-connected PV-wind power systems by considering minimum life cycle cost of the system. Based on unmet load, excess electricity, RF, NPC and CO_2 emissions percentage, optimal sizing of grid-connected PV system was presented by Ramli et al. [17]. Kolhe et al. [18] investigated the optimum configuration of a hybrid system for a rural area by using techno-economic analysis. COE, annual average wind speed and solar irradiation were considered as the sensitivity parameters. Chauhan and Saini [19] proposed a methodology to utilize the renewable resources such as small hydro, biomass, biogas, solar and wind to fulfill the demand of the study area. They also discussed the barriers and issues related to the system implementation.

In view of the literature and the electrification of remote rural areas using renewable energy, the role of integrated renewable/HES has been found very much encouraging and therefore MNRE government of India has taken the task of off-grid electrification of remote rural areas using renewable energy. This aspect has led us to select the said remote area in Almora district of Uttarakhand.

The above literature indicates that lot of work has been reported on development of HES using wind-diesel/SPV-diesel/SPV-wind-diesel etc. but not much work by using MHP and biomass energy as the main component of HES. Some work done by AHEC in this aspect is already reported [19–22].

This paper is categorised into 9 sections. Section 1 presents the introduction with the description of the scenario of rural electrification and provides solution that how HES is an alternate for solving this problem. It also includes the energy scenario of the world in terms of conventional and non-conventional sources. Section 2 discusses the profile of the study area with the population and number of households. Section 3 gives the overview about HOMER software. Section 4 presents demand and available resources of the study area with mathematical formulations. Section 5 presents four different types of model based on the available resources, to study the area. Section 6 gives an overview about dispatch strategy used in the present study. Section 7 provides