Renewable Energy 62 (2014) 388–398

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Off-grid electricity generation with renewable energy technologies in India: An application of HOMER

Rohit Sen [a], Subhes C. Bhattacharyya [b,*]

[a] TERI, New Delhi, India
[b] Institute of Energy and Sustainable Development, De Montfort University, The Queens Building, The Gateway, Leicester LE1 9BH, UK

ARTICLE INFO

Article history:
Received 10 December 2012
Accepted 15 July 2013
Available online 24 August 2013

Keywords:
Hybrid systems
Off-grid electrification
HOMER
India

ABSTRACT

Renewable energy-based off-grid or decentralised electricity supply has traditionally considered a single technology-based limited level of supply to meet the basic needs, without considering reliable energy provision to rural consumers. The purpose of this paper is to propose the best hybrid technology combination for electricity generation from a mix of renewable energy resources to satisfy the electrical needs in a reliable manner of an off-grid remote village, Palari in the state of Chhattisgarh, India. Four renewable resources, namely, small-scale hydropower, solar photovoltaic systems, wind turbines and bio-diesel generators are considered. The paper estimates the residential, institutional, commercial, agricultural and small-scale industrial demand in the pre-HOMER analysis. Using HOMER, the paper identifies the optimal off-grid option and compares this with conventional grid extension. The solution obtained shows that a hybrid combination of renewable energy generators at an off-grid location can be a cost-effective alternative to grid extension and it is sustainable, techno-economically viable and environmentally sound. The paper also presents a post-HOMER analysis and discusses issues that are likely to affect/influence the realisation of the optimal solution.

1. Introduction

With about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010 [1], the challenge of providing reliable and cost-effective services remains one of the major global challenges facing the world in this century. Although grid extension still remains the preferred mode of rural electrification [2], extension of the central electricity grid to geographically remote and sparsely populated rural areas can either be financially unviable or practically infeasible. Off-grid options can be helpful in such cases.

Moreover, the efforts in using renewable energies have often focussed on single technologies. For example, Solar Home Systems (SHS), solar photovoltaic systems and micro-hydropower have been widely used, but such options are often unable to cater to consumers' needs adequately and reliably due to limited resource availability arising from variability of resources. Reliance on a single technology generally results in an over-sizing of the system, thereby increasing the initial costs. A hybrid system design can overcome the intermittent nature of renewable energy sources (RES), the over-sizing issue and enhance reliability of supply. Yet, hybrid systems have received limited attention due to their increased complexity and hardly any work has considered the issue of reliable supply of electricity in a rural context.[1]

The purpose of this study is to find the best combination of RET from the available resources in a given village location that can meet the electricity demand in a reliable and sustainable manner and to analyse whether such a hybrid option is a cost effective solution or not. To achieve this objective, we use an example of an Indian village, estimate the potential demand, identify the available resources, model electricity generation based on multiple combinations of RETs with the application of HOMER software, select the best option based on the cost of electricity generation and then compare these performance indicators to grid extension related costs. Our choice of the tool is influenced by its popularity, ease of

Abbreviations: COE, cost of energy; km, kilometre; EDL, economical distance limit; RET, renewable energy technology; RES, renewable energy sources; GHG, green house gases; LCC, life cycle cost; LUCE, levelized unit cost of electricity; NPC, net present cost; O&M, operation and maintenance; BET, bio energy technology; T&D, transmission and distribution; SPV, solar photovoltaic's; BDG, bio-diesel generator; SHP, small hydropower; B100, 100% pure biodiesel; DG, diesel generator; MNRE, Ministry of New & Renewable Energy, India.

* Corresponding author.
E-mail addresses: rohit.sen@teri.res.in (R. Sen), subhesb@dmu.ac.uk, subhes_bhattacharyya@yahoo.com (S.C. Bhattacharyya).

[1] By reliable supply we imply round-the-clock supply or supply on demand. In most studies, a limited period of supply is considered for rural areas. This is not the case in this study.

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.07.028

use and flexibility. Despite our reliance on HOMER, our contribution arises from four novel features: 1) most of the studies in the past have considered wind turbines, solar power and diesel technologies whereas we have considered four renewable technologies namely micro-hydro, solar PV, wind turbines and bio-diesel thereby pushing the hybrid technology combinations; 2) the reliability of supply, which has not received adequate attention in the literature, is considered as a main supply objective; 3) we have included productive use of electricity in commercial and agricultural activities in addition to domestic energy needs, thereby enlarging the scope of the study; and 4) we have gone beyond a typical HOMER application by considering pre and post HOMER analysis (discussed in Sections 3.1 and 5 in more detail).

The organisation of the paper is as follows: Section 2 presents a review of related studies; Section 3 briefly presents HOMER, Section 4 presents the case study and results obtained from the study. Section 5 then presents the post-HOMER analysis, while concluding remarks are presented in Section 6.

2. Literature review

The purpose of the literature review presented here is twofold: first, this provides evidence of knowledge gap that justifies the need for this work; and second, it also provides support for the methodology used in the study and is a source of information for comparison, triangulation and referencing. Given the above purpose, we use the literature to show the limitations of existing studies by focussing mainly on studies that relied on HOMER as the analytical tool.

HOMER (Hybrid Optimisation Model for Electric Renewables), developed by NREL (National Renewable Energy Laboratory, USA) appears repeatedly in the literature as a preferred tool. It can handle a large set of technologies (including PV, wind, hydro, fuel cells, and boilers), loads (AC/DC, thermal and hydrogen), and can perform hourly simulations. HOMER is an optimization tool that is used to decide the system configuration for decentralized systems. It has been used both to analyse the off-grid electrification issues in the developed as well as developing countries. In the case of developed countries, often advanced fuel systems such as hydrogen are considered. Examples of such studies include the following Khan and Iqbal [3] who investigated the feasibility of a hybrid system with hydrogen as energy carrier in Newfoundland, Canada; Barsoum and Vacent [4]; Karakoulidis et al. [5], Giatrakos et al. [6] and Türkay and Telli [7].

For developing countries, a large number of studies exist and a detailed review of this literature is beyond the scope of this paper. Instead we focus on a selected set for our purpose. Givler and Lilienthal [8] conducted a case study of Sri Lanka where they identified when a PV/diesel hybrid becomes cost effective compared to a stand-alone small solar home systems (50 W PV with battery). This study considers an individual household base load of 5 W with a peak of 40 W, leading to a daily load average of 305 W-hours. Through a large number of simulations, the study found that the PV-diesel hybrid becomes cost effective as the demand increases. However, this study focuses on the basic needs as such and does not include productive use of energy.

Munuswamy et al. [9] compared the cost of electricity from fuel cell-based electricity generation against the cost of supply from the grid for a rural health centre in India, applying HOMER simulations. The results showed beyond a distance of 44 km from the grid, the cost of supply from an off-grid source is cheaper. This work just considered the demand of a rural health centre and was not part of any traditional rural electrification programme.

Hafez and Bhattacharya [10] analysed the optimal design and planning of renewable energy-based micro-grid system for a hypothetical rural community where the base load is 600 kW and the peak load is 1183 kW, with a daily energy requirement of 5000 kWh/day. The study considers solar, wind, hydro and diesel resources for electricity generation. Although the study considers electricity demand over 24 h, the purely hypothetical nature of the assumptions make the work unrealistic for many off-grid areas of developing countries.

Lau et al. [11] analysed the case of a remote residential area in Malaysia and used HOMER to analyse the economic viability of a hybrid system. The study uses a hypothetical case of 40 households with a peak demand of 2 kW. The peak demand is 80 kW and the base demand of around 30 kW is considered in the analysis. Although such high rural demand can be typical for Malaysian conditions, it is certainly not true for others. The study also does not consider any productive use of electricity.

Similar case studies are presented in other studies as well. For example, Himri et al. [12] present a study of an Algerian village; Nandi and Ghosh [13] discuss the case of a Bangladeshi village, while Nfah et al. [14] and Bekele and Palm [15] provide case studies of Cameroon and Ethiopia respectively. Table 1 summarises the technology choices, demand focus and country of application of these studies.

It can be seen that the hybrid options have often considered a limited set of technologies. Moreover, most studies concentrate on supplying electricity merely for domestic purposes and do not take into account the electricity demand for agricultural, irrigation, community purposes and for small-scale business units for the socio-economic development of the whole region. The load profiles are also not carefully considered in many cases. These issues are considered in the present study, thereby bridging the knowledge gap.

Table 1
Selected examples of hybrid technology analysis using HOMER.

Reference	Technology application	Country of application	Supply duration/type
Givler and Lilienthal [8]	PV-battery–diesel	Sri Lanka	Basic needs
Hafez and Bhattacharya [10]	PV, Wind, Hydro, Diesel, Battery	Hypothetical	24 h service but unrealistic demand profile for a rural area of developing countries.
Lau et al. [11] (2010)	PV-diesel hybrid	Malaysia	24 h service but uses a high demand profile for a rural area and does not use any productive load.
Himri et al. [12]	Wind-diesel hybrid	Algeria	Adding wind turbine to an existing diesel-based supply; Limited technology options.
Nandi and Ghosh [13]	Wind-PV-Battery	Bangladesh	Solar and wind hybrid; no productive demand
Nfah et al. [14]	PV, Micro-hydro, LPG generator, battery	Cameroon	Diesel as main generator supplemented by PV and micro-hydro, load based on grid-connected urban households of Uganda was used.
Bekele and Palm [15]	PV-wind hybrid	Ethiopia	PV and wind hybrid, randomised load profile from hypothetical load data.