Renewable Energy 36 (2011) 2238–2244

Contents lists available at ScienceDirect

Renewable Energy

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

Techno-economic analysis of a stand-alone hybrid photovoltaic-diesel–battery-fuel cell power system

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ARTICLE INFO

Article history:
Received 22 August 2010
Accepted 6 December 2010

Keywords:
Hybrid system simulation
Techno-economical analysis
Photovoltaic
Battery
Diesel generator
Hydrogen

ABSTRACT

The main objective of this work is to model a renewable energy system that meets a known electric load with the combination of a photovoltaic (PV) array, a diesel generator and batteries. The replacement of conventional technologies with hydrogen technologies is examined. The analysis utilizes the power load data from an electric machinery laboratory located in Kavala town, Greece. The modeling, optimization and simulation of the proposed system were performed using HOMER software. Different combinations of PV, generators, and batteries sizes were selected in order to determine the optimal combination of the system on the basis of the Net Present Cost (NPC) method.

1. Introduction

Electrical energy demand is greater than ever before. Rising concerns about the effects of global warming and declining fossil fuel stocks have led to increased interest in renewable energy sources. From a Danish case point of view a 100% renewable energy supply based on domestic resources is possible, although the design of such a system is a very complex process [1]. The comparison of seven flexible technologies is examined by using the freeware model energyPLAN. Heat Pumps (HP) and flexible demand are the most promising technologies in respect of costs [2]. Solar energy is an inexhaustible, site-dependent, clean (does not produce emissions that contribute to the greenhouse effect), and potential source of renewable energy. Although, solar energy is enormous, but PV-driven power system is still an expensive option [3]. PV systems have the advantage of minimum maintenance and easy expansion (upsizing) to meet growing energy needs. PV systems also produce electricity during the times when we demand it most, on hot sunny days coinciding with our peak electricity consuming periods.

Stand-alone diesel gensets (relatively inexpensive to purchase) are generally expensive to operate and maintain especially at low load levels [4]. Energy supply systems based on renewable energy sources (RES) require energy storage because of their fluctuation and the insufficient certainty of supply. An established way of storage is the use of a diesel system. PV-generated electricity stored in batteries can be retrieved during nights. Use of diesel system with PV-battery reduces battery storage requirement. Research indicates that hybrid combination of PV/diesel/battery system (represents an economically acceptable compromise between the high capital cost of PV autonomous system and high O&M and fuel cost of fossil fuel generators) is a reliable source of electricity [5]. However, there are environmental concerns associated with the use of batteries, thus other alternatives are sought for this application. Energy storage based upon converting electricity to hydrogen gas and back is seen as a possible answer that could remove these problems (except, in the present, the problem of cost) [6]. The electrolysers technologies may prove important in 100% renewable energy systems with large amounts of intermittent renewable energy and in which biomass is a limited resource [2]. Solar hydrogen is described as a potential energy storage medium to offset the variability of solar energy [7,8].

The hybrid systems considered in the analysis consist of different combinations of PV modules (different array sizes) supplemented with battery storage system and diesel generators. The study evaluates the feasibility of utilizing solar/PV energy to meet the electricity requirements of the electric machinery laboratory located in Kavala town (40°56′ N, 24°23′ E, Greece, Fig. 1) in conjunction with the conventional sources of electricity (diesel generators).

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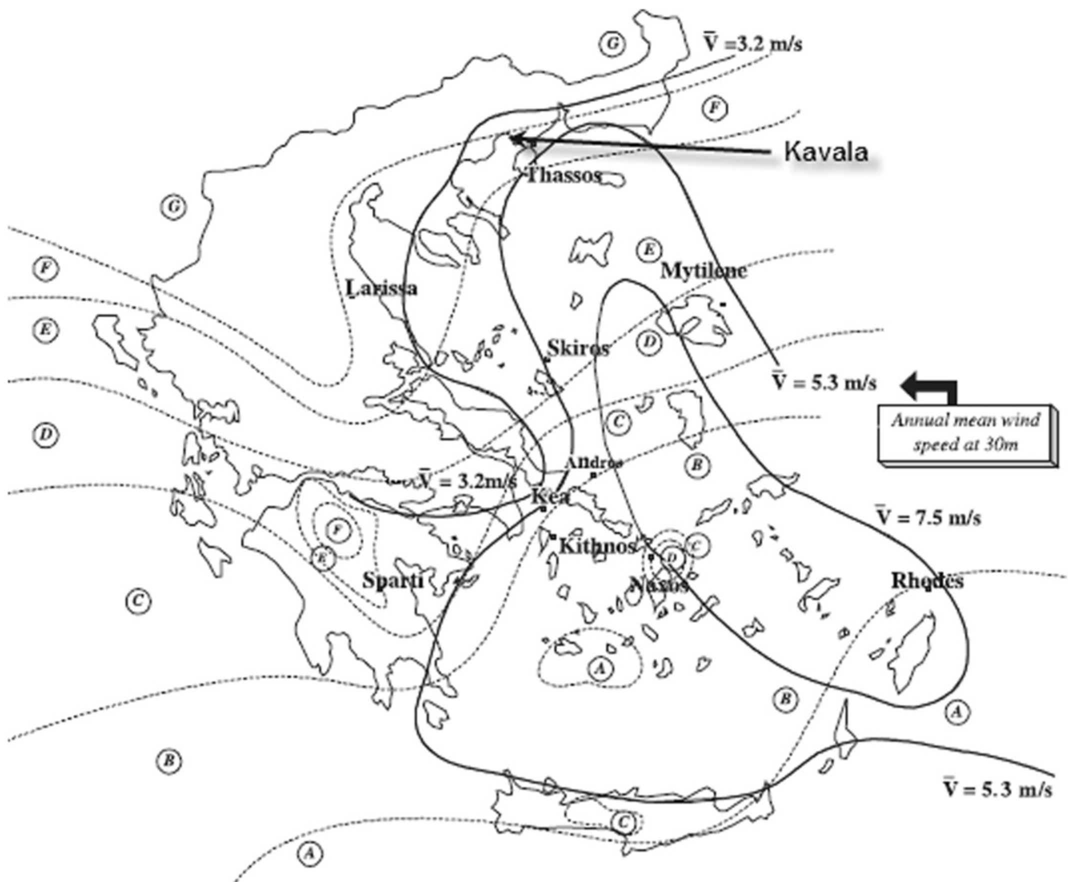
0960-1481/$ – see front matter
doi:10.1016/j.renene.2010.12.003



ZONE	k Wh / m ^{2}
A	> 1650
B	1600 - 1649
C	1550 - 1599
D	1500 - 1549
E	1450 - 1499
F	1400 - 1449
G	< 1399

Fig. 1. Location of the proposed site.

The paper examines the techno-economic aspects of replacing diesel generators with batteries by fuel cells, an electrolyser and a conventional hydrogen storage tank. Simulation, comparison and economic evaluation of both systems is performed. Sensitivity analysis taking into account possible future diesel prices, different solar radiation and average daily electric demand values is presented. Analysis shows that the replacement of the diesel generator and battery bank leads to a significant increase in the PV nominal capacity. Cost of Energy (COE) is particularly high in the PV-hydrogen energy system due to high capital costs of the fuel cell and electrolyser. Similar combination of energy sources has not been studied in Kavala, Greece. The National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewables (HOMER) software has been used to carry out the techno-economic viability of hybrid power systems. HOMER is a tool or computer-model that facilitates design of stand-alone electric power systems [9]. Analysis with HOMER requires information on resources, economic constraints, and control methods. It also requires inputs on component types, their costs, efficiency etc. Sensitivity analysis could be done with variables having a range of values instead of a specific number. HOMER as well as HYDROGEMS, the BCHP Screening Tool and TRNSYS 16 primarily focus on stand-alone applications of renewable energy such as single-building, local community, or single-project applications [10].

2. System description

2.1. Electrical load

The analysis utilizes the power load data from the electricity machinery laboratory at the Kavala Institute of Technology (Electrical Engineering Department). Fig. 2 shows the daily load profile for a 1-year cycle. There are four workplaces including several types of machines (transformers, AC and DC motors and generators), the educational period is from October to June, in this period the working hours for the experiments, research and theory are from 8:00 to 18:00 every day. Low energy consumption is observed during the summer months (July to September). Table 1 presents the basic auxiliary energy requirements of the laboratory.