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Economic analysis of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions—A step to clean future

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Abstract

The growing concerns of global warming and depleting oil/gas reserves have made it inevitable to seek energy from renewable energy resources. Many nations are embarking on introduction of clean/renewable solar energy for displacement of oil-produced energy. Moreover, solar photovoltaic (PV)–diesel hybrid power generation system technology is an emerging energy option since it promises great deal of challenges and opportunities for developed and developing countries. The Kingdom of Saudi Arabia (K.S.A) being enriched with higher level of solar radiation, is a prospective candidate for deployment of solar PV systems. Literature indicates that commercial/residential buildings in K.S.A. consume about 10–45% of the total electric energy generated. The aim of this study is to analyze long-term solar radiation data of Dhahran (East-Coast, K.S.A.) to assess the techno-economic feasibility of utilizing hybrid PV–diesel–battery power systems to meet the load of a typical residential building (with annual electrical energy demand of 35,120 kWh). The monthly average daily solar global radiation ranges from 3.61 to 7.96 kwh/m^2. National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewable (HOMER) software has been employed to carry out the present study. The simulation results indicate that for a hybrid system composed of 4 kWp PV system together with 10 kW diesel system and a battery storage of 3 h of autonomy (equivalent to 3 h of average load), the PV penetration is 22%. The cost of generating energy (COE, US$/kWh) from the above hybrid system has been found to be 0.179 $/kWh (assuming diesel fuel price of 0.1$/l). The study exhibits that for a given hybrid configuration, the operational

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hours of diesel generators decrease with increase in PV capacity. The investigation also examines the effect of PV/battery penetration on COE, operational hours of diesel gensets for a given hybrid system. Concurrently, attention is focussed on un-met load, excess electricity generation, fuel savings and reduction in carbon emissions (for different scenarios such as PV–diesel without storage, PV–diesel with storage, as compared to diesel-only situation), COE of different hybrid systems, cost of PV–diesel–battery systems, etc.
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Keywords: Solar irradiance; PV modules; Residential loads; Battery; Diesel generators; Carbon emissions

Contents

1. Introduction

Due to rapid escalation in world's population and development, fossil fuel (oil/gas) is extensively used for power generation. Over dependence on fixed/limited fossil fuels for large-scale electricity generation is very alarming. Hence, exploitation of renewable sources of energy is imperative to mitigate energy crisis and eventually to subside environmental degradation (due to burning of fossil fuels) in foreseeable future. The Kingdom of Saudi Arabia's (K.S.A.) total installed electricity generation capacity has increased significantly (from 1141 MW in 1975 to 27,000 MW in 2002; also the peak demand is expected to be 59,000 MW in 2020) during the last two decades [1,2]. In particular, Dhahran's peak electricity demand has escalated from 7317 MW in 1995 to 8332 MW in 2001 [3,4]. The above increase can be attributed to rapid growth in residential, commercial, and industrial sectors. Literature reveals that commercial/residential buildings in Saudi Arabia consume 10–45% of the total electric energy consumed [1]. Increased rate of electric energy consumption constitutes one of the biggest problems being encountered by the electric companies in the K.S.A. In order to cope with the increasing electricity consumption trends, it is desirable to explore every possible avenue for generating more energy [4]. One of the options to overcome this profound energy issue is by exploitation of indispensable renewable sources of energy such as solar energy [5]. Since K.S.A. is blessed with high solar radiation levels, an appreciable portion of its energy needs may be harnessed from solar energy. Solar radiation intensities of geographically different provinces of Kingdom are presented in Table 1. However, the present work (as a case study) concentrates on Dhahran.

Solar energy is one of the sustainable/potential/in-exhaustible, site-dependent, benign/nature-friendly (does not produce emissions that contribute to greenhouse effect) source of

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