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Feasibility analysis of standalone photovoltaic electrification system in a residential building in Cyprus

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ABSTRACT

This research focuses on the design phases and economic analysis of a standalone photovoltaic system to electrify a house in the rural fringe of Famagusta, Cyprus. The designed system has the capability to cover residents' electricity demand (17.23 (kW h/day)) during the winter (with the lowest solar irradiation). Utilizing mathematical model, the PV panels area, PV peak power, the battery capacity, inverter and charge controller sizes were determined to be 46.73 (m^2), 7.5 (kW), 44.78 (kW h), 2 (kW) and 350 (A) respectively. Moreover, the life cycle cost analysis was investigated. The life cycle cost of the system was found to be [TRY] 54,560 whereas the annualized life cycle cost and unit price of electricity was calculated to be around [TRY] 2700 and [TRY] 0.43 for each kilowatt-hour. It was concluded that a standalone photovoltaic system is economically and technically feasible and a viable technology for the electrification of a house in Cyprus.

Contents

1. Introduction

Global energy consumption growth is a challenging and controversial issue in the current century in most countries [1]. Primary energy, which is available in nature, provides the world energy demand. Primary energy could be found in the form of renewable or non-renewable source such as oil, gas, coal, wind, sun and uranium. Primary energy consumption rose by 2.3% in 2013, with an acceleration of +1.8% throughout 2012 in the world [2]. Fossil fuels are currently the world's main energy source. They will continue to generate 80% of the world's energy until 2030 [3]. The growth in fossil fuel consumption leads to the elevation of CO_2 emission and thus, global warming [2]. However, global ecological concerns about the usage of fossil fuels have led to attempts to decrease the rate of fossil fuel consumption by developing renewable alternative energy sources [4], for instance, solar, wind, biomass and hydroelectric energy. Without any doubt, it is important to have more sustainable energy sources that are less

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harmful to the environment, in order to meet the rising demand for electricity. This need has pushed the concept of renewable and sustainable energy to the foremost of environmental sustainability debates. Solar photovoltaic power has been found among the available alternative to have an especially large capability to generate electricity [5] nevertheless, the most barriers to a more ubiquitous utilization of photovoltaic panel are that generated electricity from this source is limited to day-time, it fluctuates over the year and relies on weather condition [6].

Buildings consume 40% of the world's primary energy and generate one-third of the greenhouse gas emissions around the world [7,8]. Therefore, any improvement in renewable energy sources in buildings would have a great impact in reducing the disadvantages of fossil fuel usage.

Many attempts have been made to increase the implementation of photovoltaic panels to produce the electricity from a renewable energy source. The major dispute bound to photovoltaic system is its high initial cost of installation. However, if the proper life cycle cost analysis is performed, it could be a beneficial and environment friendly solution.

Many researches have been carried out to investigate the viability, feasibility, risk factors and financing indicators in the implementation of photovoltaic electrification systems [9,10]. A photovoltaic system was tested to provide electricity in Nigeria using a decentralized method. It was concluded that photovoltaic systems were a feasible choice to improve the electricity supply and develop the society in the Nigerian rural communities [11]. A review of electrification of photovoltaic systems in developing countries including developmental implications of electricity infrastructure shortage was provided by [12]. More than one hundred articles were reviewed and features of several alternatives available for decentralized power and environmental & economical analyses were described by [13]. The feasibility and viability of a photovoltaic system has been analyzed through various models, for instance, cost effectiveness, financial indicator model, and annualized life cycle cost model. Moreover, some analytical software such as hybrid optimization models for electricity renewal [14–16] and RETScreen [17] were used in some recent researches. A techno-economic feasibility of photovoltaic system to supply electricity for the remote villages was carried out in Palestine. It indicated that use of photovoltaic electricity is more feasible rather than diesel generators or electric grid in terms of economic point of view in rural areas [18]. A photovoltaic system was compared with fossil fuel power source in terms of net present worth in Bangladesh to determine its commercial feasibility in remote areas. It is based on foreign aid and fiscal planning of medium size renewable energy projects [19].

The possibility of installing photovoltaic system in combination with a diesel generator in a Malaysian school was investigated and it was concluded that investing a photovoltaic electrification would be beneficial under a certain critical cost value [20]. A life cycle cost analysis for different combinations of diesel generators and photovoltaic systems was investigated in an Indian school. It was found that an off-grid photovoltaic system is an appropriate alternative to reduce power requirements and becoming more and more competitive as their price continue to decrease in the future [21]. A techno-economic feasibility of photovoltaic-diesel-battery system was carried out using the HOMER software to cover rural communities' electricity demand in Iran. It gives a comparative analysis among various possible configurations of a system best suited to fulfill the electricity demands [22].

An investigation was carried out to electrify a health clinic in rural area of southern Iraq. Various combinations of photovoltaic, inverter and battery sizes were simulated. The proposed system consists of 6 (kW) photovoltaic panels, 3 (kW) inverter and 80 batteries (225 A h, 6 Volt). The electricity cost of this system was equal to 0.238 (US$ kW h^{-1}) which was calculated utilizing the life cycle cost method. It was found that this price is four times cheaper than the price of electricity which was generated by diesel generators. The analysis also illustrated that this photovoltaic system prevents the annual release of 36.8 kg CO, 30 kg SO_2, 4.08 kg HC, 429 kg NO_x, 14,927 kg CO_2 and 278 f kg suspended particles in comparison with diesel generators [23]. A similar study was conducted to determine the optimal size of a photovoltaic unit in Oman. It was resulted that PV array of 700 Watt rated capacity generated around 1300 kilowatt-hour per year. The unit price of energy was figured out to be 0.561 ($/kW h) in comparison to diesel generator cost of 0.558 ($/kW h). Finally, it was concluded that photovoltaic system is an attractive alternative both on technical and economic factors in Oman [24]. Additionally, more researches are detailed in Table 1 below.

The photovoltaic panels' lifetime is one of the critical factors in life cycle cost and feasibility analyses. Table 2 illustrates an overview on previous researches with regard to photovoltaic panels' lifetime.

Table 1
Different researches on photovoltaic design and its life cycle cost assessment.

Required load	System specification	Results	Country	Ref.
5.5 kW h/day	PV size: 11.3 m^2, 1356 Wp Batt. size: 6 Pcs, 12 V, 250 A h	Electricity price: 0.74 $/kW h	EGY	[46]
5.5 kW h/day	PV size: 4 kW Batt. size: 6 Pcs, 12 V, 200 A h	Initial capital cost: $9700	DZA	[50]
24.4 MW h/year	PV size: 19 kW Batt. size: 12 Pcs, 2 V, 3000 A h	Electricity price: 0.247 $/kW h	IRN	[51]
83.2 MW h/year	PV size: 41.6 kW Batt. capacity: 228 kW h	Electricity price: 0.240 $/kW h LCC: $542,618	TUN	[47]
61.7 MW h/year	PV size: 27 kW Wind turbine size: 39 kW Batt. size: 370 Pcs, 6 V, 225 A h	Electricity price: 0.363 $/kW h (hybrid) 0.525 $/kW h (solar) 0.646 $/kW h (wind)	BGD	[48]
8.7 MW h/year	PV size: 6.28 kW Batt. size: 16 Pcs, 12 V, 220 A h	Electricity price: 0.657 $/kW h Net present cost: $49,711	BRA	[49]
219 kW h/year	PV size: 150 W Batt. size: 60 A h	Electricity price: 0.145 $/kW h (with subsides) 0.258 $/kW h (without subsides)	IND	[40]
1825 kW h/year	PV size: 2 kWWind turbine size: 1 kWBatt. size: 12 V, 200 A h	Electricity price: 1.232 $/kW h Net present cost: $28,975	IND	[52]
2154 kW h/year	PV size: 1928 Wp, 12.85 m^2 Batt. capacity: 9641 W h	Electricity price: 0.141 $/kW h Life cycle cost: $4361.5	PAK	[35]
22 MW h/year	PV size: 750 W Wind turbine size: 900 W Batt. size: 14 Pcs, 12 V, 100 A h	Electricity price: 0.36 $/kW h Annualized cost: $589,31	IND	[58]
270 kW h/day	PV size: 30 kW Wind turbine size: 40 kW Diesel generator: 25 kW Batt. capacity: 222 kW h	Electricity price: 0.34 $/kW h Net present cost: $ 296,000	LKA	[59]