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Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design

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ABSTRACT

Ensuring energy security increasingly requires expanding both yield and resilience of supply through source diversification. In this study, the current energy situation of Nigeria is presented through a detailed literature review. The survey reveals that access to the national grid is limited, and the power delivered to areas classified as urban with grid connection is very unreliable. An initial assessment of the potential utilization of solar based technologies for electricity generation is presented for three strategically located Nigerian cities of Onitsha, Kano and Lagos. These cities are known for their large commercial activities, and their frequent power outages hinder their business and socio-economic development. The solar resources are modeled using synthetic hourly meteorological data for a complete year in typical meteorological year format. On an annual basis, Kano has the largest average daily global horizontal resources (6.08 kWh m^{-2}), while these resources are practically equal for Onitsha (4.43 kWh m^{-2}) and Lagos (4.42 kWh m^{-2}). For dual axis tracking, which maximizes utilization of solar resources, the monthly range of daily average solar insolation for all locations varies between 3.65 kWh m^{-2} and 8.00 kWh m^{-2}. A standalone photovoltaic system on a tilted surface is sized to meet a representative household demand based on intuitive and numerical simulation sizing methodologies. These sizing methodologies are general and can be applied to any location. The estimated PV capacity and the corresponding unit cost of electricity ranged from 1.26 kW_p at 0.206 USD kWh^{-1} to 2.92 kW_p at 0.502 USD kWh^{-1} for the selected cities. The results show that the unit cost of electricity from the proposed standalone PV systems is lower than that for the widely-utilized diesel generators. It is concluded that standalone PV electricity is technically and economically viable for urban residential application in Nigeria considering the current infrastructure and energy policies.

Contents

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1. Introduction

In recent years, the burning of fossil fuels for electricity generation is being questioned due to its contributions to ozone depletion, acid rain and global warming [1]. As a result, renewable resources and technologies are being promoted globally as sustainable alternatives to these fossil fuel based resources [2–4]. These renewable resources and technologies include but are not limited to wind, biomass, hydropower, geothermal, and solar, and have been utilized with proven results [4–9]. While some of the studies investigated their technical feasibility in terms of design, performance, and sizing methodologies [5,7,8], other studies investigated the social, economic and environmental implications of utilizing these technologies under different conditions [4,6,9]. The advantages of these renewable energy options include the following: (i) guaranteeing energy security and promoting economic advancement [2]; (ii) reducing or eliminating fuel costs and conserving finite fossil fuel resources [3]; and (iii) environmental benefits and internalization of external costs [4]. In addition, Okoye and Atikol [10] mentioned that the inexhaustible nature of these resources makes them ideal alternatives to conventional fossil fuel resources. Currently, one major disadvantage of the use of renewable energy resources besides the issue of dispatchability is that they are location dependent and often cannot be transported as easily as conventional non-renewable energy resources from the place of abundance to where they are needed. Among all renewable energy alternatives, solar stands out as a promising and valuable source for future electricity generation in both urban and rural areas. Kammen [11] and Zhou et al. [12] stated that solar and wind energies together with the allied technologies are the most developed sources of renewable alternatives. In addition, Sungur [13] stated that the amount of energy which can be generated from solar technologies depends entirely on the location's available solar resources and the conversion efficiency of the adopted system. Therefore, case studies involving solar resource assessment and the associated energy conversion technologies become very important for favorable adoption and deployment.

As a developing country, Nigeria is one of the most populous nations in Africa with an estimated population of 170 million in 2014 growing at 2.3% annually [14]. The country is located at latitude 4–14°N and longitude 2–15°E between the Equator and the Tropic of Cancer, and covers a total surface area of 923,768 km^2. In 2012, Nigeria's gross domestic product (GDP) per capita was 1557 USD with an estimated annual growth of 5.8% [15]. Nigeria has features characteristic of a tropical climate and suffers from a severe energy crisis. Soneye and Daramola [16] identified energy as an important stimulant for social and economic growth. The energy crisis affects both rural and urban populations. Additionally, Adaramola and Oyewola [17] stated that the energy challenge is more pronounced among rural dwellers as approximately 70 million people in the rural communities do not have access to grid electricity. Subsequently, Ohunakin et al. [18] revealed that about 51% of the entire population resides in the rural areas. However, while rural areas suffer from lack of access to the grid, the power delivered to areas classified as urban with grid connection is very unreliable. As a result, urban areas often witness several days of darkness within a week as load shedding is continuously and widely practiced. The report of survey research by Soneye and Daramola [16] revealed that more than 50% of the household in the urban area of Ibadan connected to the national grid receive less than 4 h of electricity on a daily basis. Consequently, diesel generators are widely utilized in these urban areas and the associated environmental and social impact of fumes and noise in those cities are significant. Moreover, the recent upsurge in the price of diesel with the removal of the federal government subsidy on petroleum products has compounded these problems. A recent study of Ohijeagbon and Ajayi [19] showed that the unit cost of electricity from diesel standalone systems is relatively high at 0.62 USD kWh^{-1}; therefore, urban areas in Nigeria also suffer from acute energy supply problems. The motivation for this work is to identify initial strategies to reduce Nigeria's energy crisis in order to sustainably enhance social and economic growth by focusing on urban areas. In the remainder of this introduction, an overview of Nigeria's current energy is given and a review of algorithms for meteorological data models is presented. This review identifies a clear gap in the literature related to not only energy scarcity in the commercial cities of Nigeria but also on the use of hourly meteorological data in the assessment of the available solar energy resources which can be utilized by any known solar technology. In the remaining sections of this paper, the gap is addressed through resource assessment, and the design and economic analysis of standalone photovoltaic systems.

The reported peak electricity generation capacity of Nigeria as of February 2015 is 3342 MW compared to an estimated peak demand of 12,800 MW representing a power deficit of 74% [20]. This is in contrast to 2013 when the reported peak generation was 4362 MW and estimated demand was 10,144 MW [18], which indicates that the peak generation is decreasing while the demand is rapidly increasing. As expected from a country with low generating capacity relative to demand such as Nigeria, some residents have access to electricity for only a limited number of hours in a week. In Table 1, the Nigerian power generating capacity is presented. The total installed electricity generation capacity consists of 22% from hydropower plants and 78% from thermal power plants utilizing fossil fuels. The hydro and thermal power plants have a weighted average availability of 49.1%. Ibitoye and

Table 1
Power generation capacity of Nigeria [22].

Power plant	Installed capacity (MW)	Average availability (%)
Hydro Power Plants		
Kainji	760	54.3
Shiroro	600	65.0
Jebba	578	74.7
Thermal Power Plants		
Egbin	1320	62.1
Afam II, IV, V, VI	1166	39.2
Delta II-IV	900	38.1
Sapele	720	17.4
Olorunshogo I, II	710	45.6
Okpai	480	92.0
Geregu	414	50.4
Omotosho	335	35.2
AES	302	68.9
Ibom G. S	155	53.5
Omoku	150	53.5
Ajaokuta G. S	110	0.0
Trans-Amadi	100	32.6
	8800	49.1