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# Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria

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ABSTRACT

The possibility of using hybrid energy system for electricity generation in rural and semi-urban areas in the Northern part of Nigeria was investigated in this study. The global solar radiation data and residential energy consumption in Jos, (in Plateau state) located on the latitude of 9° 52′ N and longitude of 8° 54′ E are used. Hybrid Optimization Model for Electric Renewable (HOMER) software has been employed to carry out the present study. At current diesel price of $1.1/L and annual mean global solar radiation of 6.00 kWh/m$^2$/day, it was found that PV/Generator/Battery hybrid system is economically the most suitable option as a stand-alone electricity generating system in this location and other similar locations in the Northern part of Nigeria. The optimal simulation results indicate that the levelised cost of energy for this hybrid energy system varies between $0.348/kWh and $0.378/kWh depending on the interest rate. These costs are lower than the cost of using diesel generator only (without battery) which varies between $0.417 and $0.423 per kWh. It was further observed that there is a significant reduction in emissions of greenhouse gases if a hybrid energy system is used instead of only a generator based energy system. The effect of interest rate and cost of PV system on the optimal energy in this part of Nigeria was investigated and a comparison between the monthly cost of electricity using current tariff of grid connected and hybrid energy systems was also made.



## Introduction

The rapid growth of industrialization and world population which results in the increase in energy demand, depletion of finite fossil fuel resources, and climate change, has made renewable energy resources increasingly attractive as an alternative to continued over-dependence on conventional energy sources. Prior studies have shown that renewable energy sources which include solar and wind energy are clean, inexhaustible, and environment friendly, however, they are dependent on unpredictable factors such as weather and climatic conditions. Due to the intermittent nature of solar energy, a photovoltaic (PV) system alone for example, cannot satisfy load requirement on 24-h basis (Hansen, 1998). Similarly, a stand-alone wind energy system does not produce usable energy for a considerable portion of time during the year due to relatively high cut-in wind speed, which ranges from 2.5 to 4.5 m/s (Renewables Global Status Report, 2009). These noted weaknesses of renewable energy resources, can partly be overcome by taking advantage of the complementary nature of the two energy sources, i.e. using a hybrid power system. Hybrid power systems comprise at least two principal generators: usually a conventional generator powered by diesel and a renewable energy source such as wind, photovoltaic (PV), or combination of PV and wind. Several studies on the feasibility, performance, and economic viability of hybrid power systems have been conducted (e.g., Nema et al., 2009; Ajao et al., 2011; Adaramola, 2012; Adaramola et al., 2012) and they found that hybrid power systems exhibit higher reliability and lower cost of generation than systems that employ only one source of energy.

Over the last decade, several studies on hybrid power systems have been conducted in different countries such as Denmark, Spain, Germany, United States, China, and India. Detailed reviews of these studies can be found, for example, in Rehman and Al-Hadhrami, 2010; Al-Badi and Bourdoucen, 2012; Al-Badi, 2011; Ngan and Tan, 2012; and Adaramola et al., 2012 and are not repeated here. Access to a reliable and stable supply of electricity is still a major challenge for both the urban and rural dwellers in Nigeria. The challenge however, is more significant in the rural areas where only about 10% of the populace has access to electricity (Adaramola and Oyewola, 2011). Nigeria being endowed with abundant renewable energy resources, hybrid power systems are expected to offer a unique possibility in electricity generation either as grid-connected or as stand-alone systems. It is reported that about 51% of the Nigerian populace resides in remote or rural areas that have little or no access to electricity. According to Hermann, 2001, the lack of or inadequacy of energy in an economy is a potential source of social and economic poverty. In their studies,

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Afgan and Carvalho (2008), Paul (2011), Palit and Chaurey (2011), Khennas (2012), Sokona et al. (2012), and Hailu (2012), opined that access to modern energy services plays a crucial role for poverty reduction and socio-economic development. It can be inferred from these studies as well as others that the electrification of remote or rural areas is an effective instrument for the sustainable development of such regions.

Presently, due to the fluctuations in the availability and maintenance of production sources that invariably lead to a shortfall in supply, access to grid electric power in Nigeria has generally been low. In fact, the current electricity generation in Nigeria is less than 4000 MW; which is approximately 30% of the peak electricity demand forecast of 12,390 MW (Nigeria-Power-Reform, 2013). This shortfall is responsible for the high cost of power supply and poses a serious challenge to both the manufacturing sector and the overall economic development of the country. A recent survey conducted by the Manufacturers Association of Nigeria (MAN) showed that unlike in most other countries (e.g. China.) where the cost of electricity is usually 5 to 10% of production cost, in Nigeria it constitutes between 30 and 40% of the production cost. The reason for this high cost is the fact that on an average, 69% of the total energy required by the manufacturing companies is generated in-house (i.e., self-electricity generation using diesel generator) (Sme, 2013). Even assuming that it is possible to generate the required peak demand of 12,390 MW, the national grid transmission capacity in Nigeria at the moment is less than 6000 MW (Labo, 2010) and the cost of grid extension is high (ranging from $25,000 per km (Gsma, 2013), to as high as $100,000/km for 3-phase medium voltage (William and Porter, 2006). Therefore, power generation that relies on isolated mini-grids and/or small (and large) scale off-grid distribution systems will help to improve the current level of electricity access in Nigeria.

According to the World Bank, 2012 report, the average electricity consumption per capita in 2009 in Nigeria was 120.5 kWh per year which is less than 2 kWh per day for a household of five people. This per capita electricity consumption is significantly lower than those of South Africa and Egypt which as of 2008 were 4532 kWh per year and 1548.6 kWh per year respectively. As a further comparison, the per capita electricity consumption in Nigeria is less than 1% of the per capita consumption in an industrialized country such as the United States of America. Presently, the power generation resources in Nigeria are almost exclusively hydro and thermal. Although, there are quite a few other power sources such as geothermal and a number of isolated diesel generators scattered across the country as self–contained systems, these only make up at most 5% of the country's existing generation capacity requirement. As stated earlier, wind and solar power systems alone cannot satisfy typical load requirements for 24 h. Similarly, standalone diesel generator sets are generally expensive to operate and maintain, especially at low load levels. In that respect, one of the options to overcome this pronounced energy shortage is by exploitation of hybrid sources of energy.

Reviews of literature show that many studies on hybrid power system have been performed in Europe, North America, and other advanced countries, including Middle East. However, only a few studies have been reported in Nigeria (Ajao et al., 2011; Adaramola, 2012; Adaramola et al., 2012; Nwosu et al., 2012.Ajao et al. (2011), and these performed cost benefit analyses of solar-wind hybrid power system in Nigeria using HOMER software. They found that the wind-solar cell hybrid energy system would be cost effective only if there is a reduction in component cost by the installation of large numbers of the hybrid systems in a typical farm thereby lowering the investment cost per kilowatt. Adaramola (2012) examined the feasibility of an off-grid hybrid energy system for applications in Ondo state, Nigeria, while Adaramola et al. (2012) carried out a technical and economic assessment of hybrid energy systems in South-West Nigeria. Their optimal simulation results revealed that the levelised cost of energy for the hybrid energy system varies with diesel price. The integration, therefore, of both renewable energy conversion systems with diesel generators and storage facilities could be a reliable energy system in most rural areas and even for large communities in urban and semi-urban areas in Nigeria.

In this study a feasibility analysis of hybrid PV solar-diesel power system application for the remote areas in the Northern part of Nigeria (using Jos and its environs in plateau state as a case study) is presented. It is the authors' view that the information from this study will help the government in its rural energy planning framework, and also serve as input data in the design of an appropriate electrification system for use in rural and semi-urban homes or households in Nigeria.

## Location and electrical load

The daily electrical load used in this study is taken from the work of Ogbonna et al. (2011). The present study reports in detail the domestic energy consumption patterns in Jos, Northern Nigeria. Also presented is a typical daily electricity consumption profile for this location see (Fig. 1). Two prominent peak demand periods can be observed in daily electricity load profile from this figure and they occur in the: morning, between 06.00 and 09.00 and; late in the evening, between 19.00 and 21.00. These electrical load peaks are due to usual morning activities (e.g., cooking of breakfast, lighting), and cooking of supper, lighting, TV, reading (in the evening/night). They also observed that there is an insignificant difference between the daily electricity demand patterns for weekdays and weekends and the daily average demand is reported to be about 1kWh.

Based on a similar survey of ten households in Ilorin in the north central region of Nigeria, Ajao et al. (2011) reported an average electricity consumption of 400 kWh per month (or 13.3 kWh per day) per household, while Adeoti et al. (2001) found that for a typical rural area in south west Nigeria, average electricity consumption per household is about 2.3 kWh per day. However, with the current situation of unstable and unreliable supply of electricity in Nigeria, it is likely that the household electricity consumption per day in any rural area of Nigeria will be less than 2.3 kWh per day.

In this study, electrical load of 1.5 MWh per day with daily peak load of 236 kW is simulated for rural areas with population of about 1500 households and with the assumption that each household consumed 1 kWh of electricity per day. In addition, this load can serve over 750 households (at a consumption rate of 2 kWh per day) in semi-urban and urban areas. Furthermore, the 1.5 MWh/day load can be used for a big telecommunication installation, a hospital as well as for relatively big business and community centers in urban areas. For this load profile, hourly and daily variations are taken as 15% and 25% respectively.

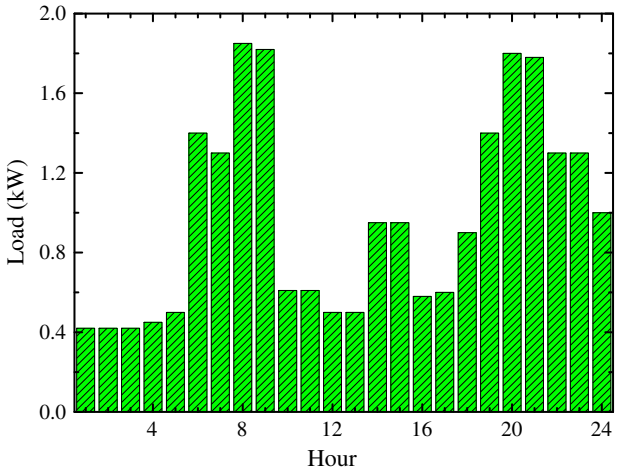


**Fig. 1.** Typical daily electricity consumption in Northern Nigeria (Ogbonna et al., 2011).